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REPORT No. 162
GEOLOGICAL SURVEY OF JAPAN
Katsu KANEKO, Director

**Wall Rock Alteration of the Kosaka
Mine, Akita Prefecture, Japan**

By
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&
Kiyoshi TAKAHASHI

GEOLOGICAL SURVEY OF JAPAN
Hisamoto-chō, Kawasaki-shi, Japan

1954

地質相談所

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Akita Prefecture, Japan**

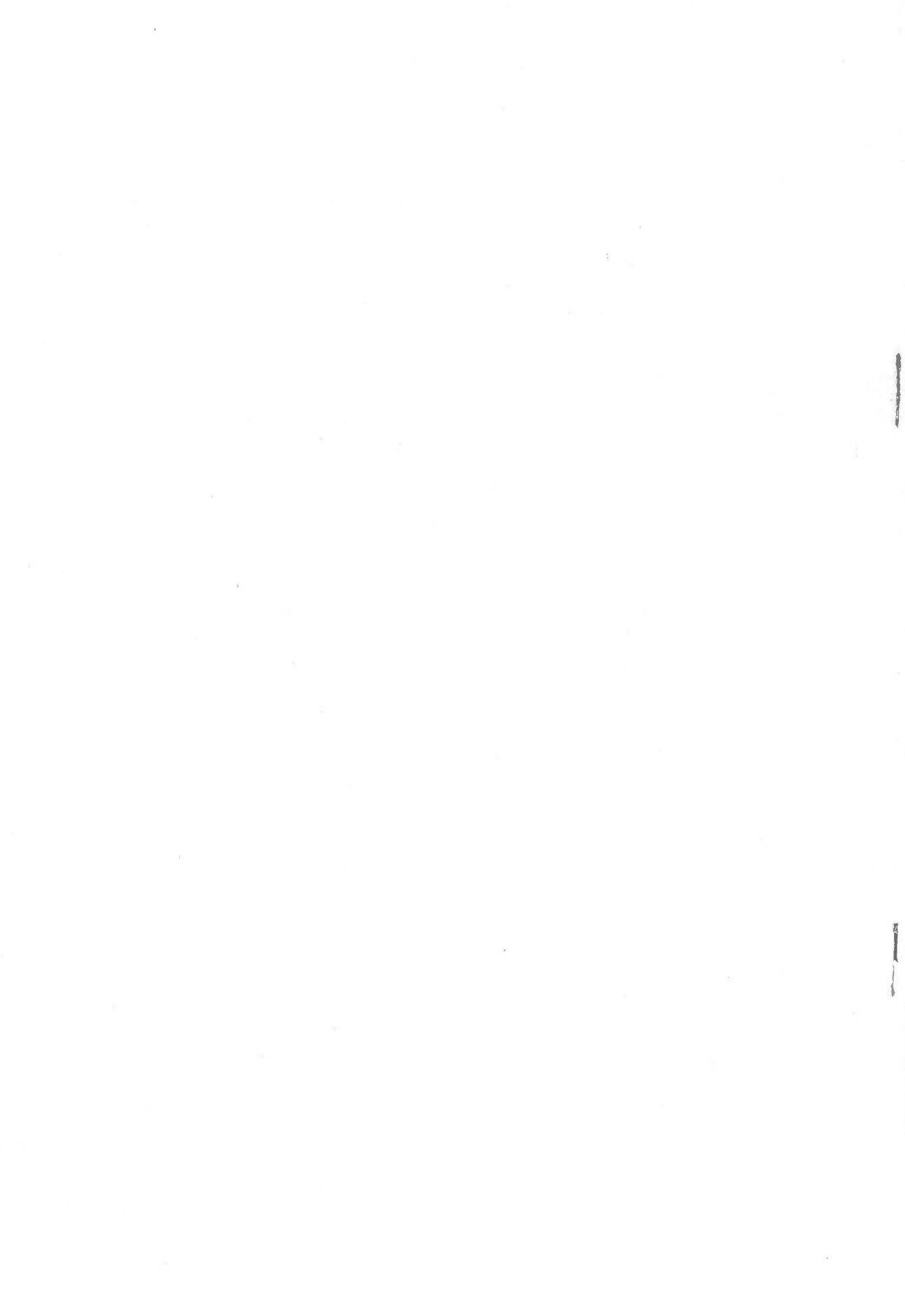
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TOKYO 1954, NOVEMBER



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Plates

Wall Rock Alteration of the Kosaka Mine, Akita Prefecture, Japan*

By

Shuichi IWAO,** Fumio KISHIMOTO & Kiyoshi TAKAHASHI

Abstract

A remarkable hydrothermal alteration of shallow seated origin is recognized in the Miocene acid volcanic rocks around the replacement copper-lead-zinc-sulphide ore deposits of the Kosaka mine, Akita prefecture, Japan. The predominance of associations of quartz, sericite, chlorite and montmorillonite in the altered rocks indicates a very limited P-T environment of alteration, i.e., the temperature about 350~400°C and the presumed depth about 2~3 kilometers.

Under these presumed circumstances, the formation of the striking zonal arrangement of the altered rocks may be interpreted as a function of increasing pH environment, with respect to the departure from the conduit of the ascending solution. The siliceous rock near around the conduit might be formed at low pH, whereas the chlorite-sericite mantle at high pH.

A functional relation between ionization potential and relative abundance of elements in the altered zones is also emphasized.

Introduction

In this paper, the present authors intend to interpret the genesis of the altered rocks which are found in the closest associations with the ore deposits of the Kosaka mine, Akita prefecture, Japan, principally on the bases of geological and petrochemical data.

Since the deposits are the typical examples of the shallow seated hydrothermal replacement copper-lead and zinc ore deposits which are embedded in the marine formations of the Neogene Tertiary, several excellent works⁴⁾⁵⁾⁶⁾ on the ore deposits have been carried out by some geologists in field and laboratory, with the following conclusions:

1) The ore deposits belong to the type of the so-called "Kuroko"[†] deposit which is inferred to have been formed by replacement of rhyolite and its tuff-breccia of more susceptible character by some ascending hot alkaline solutions.

2) The wall rocks which suffer severe hydrothermal alteration comprise sericite clayey rock and silica rock. The former occupies the center of the altered aureole and accompanies the "Oko"^{††} — chalcopyrite ore-deposits and/or the "Kuroko" —

* Dedicated to Dr. Seitaro Tsuboi, Professor of Petrology in the Tōkyō University, on the occasion of his sixtieth birthday.

** College of General Education, Tōkyō University, an ex-member of the Geological Survey of Japan.

† Called also "Black ore"

†† Called also "Yellow ore"

chalcopyrite-galena-zincblende ore-deposits, whereas the latter roughly envelops the former and encloses the patches of the so-called "Keiko"—copper bearing pyritic ore-deposits. Disseminated nodules and/or small deposits of gypsum are occasionally found in the clayey rock.

3) The age of the ore forming is later than the eruption of the Baramori rhyolite which is presumably of Miocene age, and earlier than the intrusion of the Akamori rhyolite.

4) The forming of the metal ore deposits was taken place in a general sequence as Keiko→Okō→Kuroko and attributed to be subsequent to the alteration of the country rocks.

The present authors, however, principally based on the field evidences, have arrived at somewhat different conclusions from those above cited. Namely that is as follows:

1) The sequence of zoning of the altered rocks enumerated toward outside from the center is silicified zone→sericite-chlorite zone→transitional zone→fresh rock.

2) The age of the ore forming or the wall rock alteration is somewhat younger than hitherto believed.

3) The clay mineral association of sericite and Mg-chlorite is maintained throughout the silica and main clayey zones, whereas it changes to chlorite-montmorillonite association in the peripheral zone. The first association is then persistent, without regard to the great variance in relative abundance of the two clay minerals and also of the secondary free silica.

The selective or relative migration of elements in the altered aureole caused the zonal arrangement of the altered rocks and seems to have taken place in a rough functional relation to ionization potential of the moved elements, or to pH of the solution from which the minerals deposited.

Although it may be of great importance to criticize the applicability of the results of this study to the prospecting of ores of this kind, it is beyond of the present scope of investigation.

In carrying on the field studies the authors were mostly restricted to the silica and the peripheral zones of alteration, because most of the bonanza together with the clayey wall rocks have been excavated out for long years already. Still Iwao and Kishimoto, among the present authors, could make a detailed underground survey on the silica zone—a geological mapping in the scale 1:250—along the closely spaced adits prepared for blasting the low grade copper-bearing siliceous rock to recover cement copper. The boundary features between the altered and the fresh wall rocks were closely examined at the east side cliff of the open pit. Some critical geological observations were also made in more extended area around the ore deposits.

Microscopic observation was made by Iwao, spectrochemical analysis by Takahashi, and chemical analysis by K. Maeda of the Geological Survey.

Acknowledgement

The present authors are greatly indebted to Messrs. S. Odagiri, the former Director of the Kosaka mine, S. Sumiyoshi, head of mining section of the mine, T. Hashimoto, H. Kamono, geologists of the mine and also to Mr. Z. Suzuki, head of planning section of the Dōwa Mining Company, from whom they received special facilities for field work. The silicate analysis of the rocks was partly carried out by the analyst of the Smelting Section of the mine and X-ray powder photograph of the clay minerals was taken by Mr. Otsu to whom they are also greatly obliged. Thanks are also due to prof. Dr. T. Sudo of Tōkyō University of Education for his special kindness in giving them many useful suggestions during the course of their study, and also in performing the chromatographic examination and pH measurement of the clay specimens on grinding. To Mr. Mitsuchi, the former Director of the Geological Survey of Japan also, they like to express their cordial thanks for his permanent encouragement of their works.

I Outline of geology and ore deposits

Since we have a plentiful knowledge of the general geology and the ore deposits of the mine, through Kinoshita's excellent works, it seems unnecessary to do more than denoting the difference between Kinoshita's conclusion⁴⁾ and of the present authors.

The conclusions at present are as follows:

1) The ore deposits were formed subsequent to the eruption or intrusion of the Akamori volcanic rocks.

2) The Akamori volcanics seem to have played an role of cap rocks during the time of ore forming, and the ore deposits are restricted principally in the Baramori tuff-breccia of Miocene age.

3) Although it remains ambiguous whether the bentonitization of the vitric tuff beds of the Akamori volcanic complex was continued from the wall rock alteration or not, it seems most probable that at least a part of the bentonitization preceded the ore formation.

4) Kaolinization which is recognized in a number of places along the fissures in the welded tuff of the young volcanic complex has no direct connection with the wall rock alterations around the ore deposits.

According to the conclusions, the tentative geologic

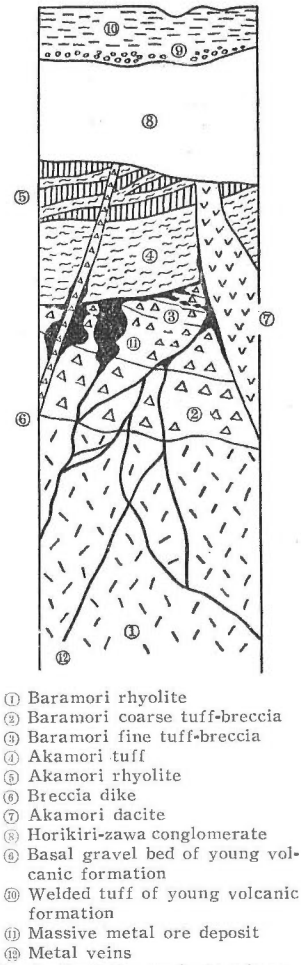


Fig. 1 Tentative geologic column of the Kosaka mining area

column of the area may be given in Fig. 1 with revision of Kinoshita's column.

The critical evidences which derived the conclusions are as follows:

1) On the east side cliff of the open pit, the fresh Akamori dacite assumes gradual transition at several meters in width toward the main clayey zone. Quite similarly altered rocks develop usually along the fault plane between the Akamori dacite and the Baramori tuff-breccia. (Fig. 2)

2) Many pebble or nodule like blocks of lead-zinc ore are contained in the tuff-breccia

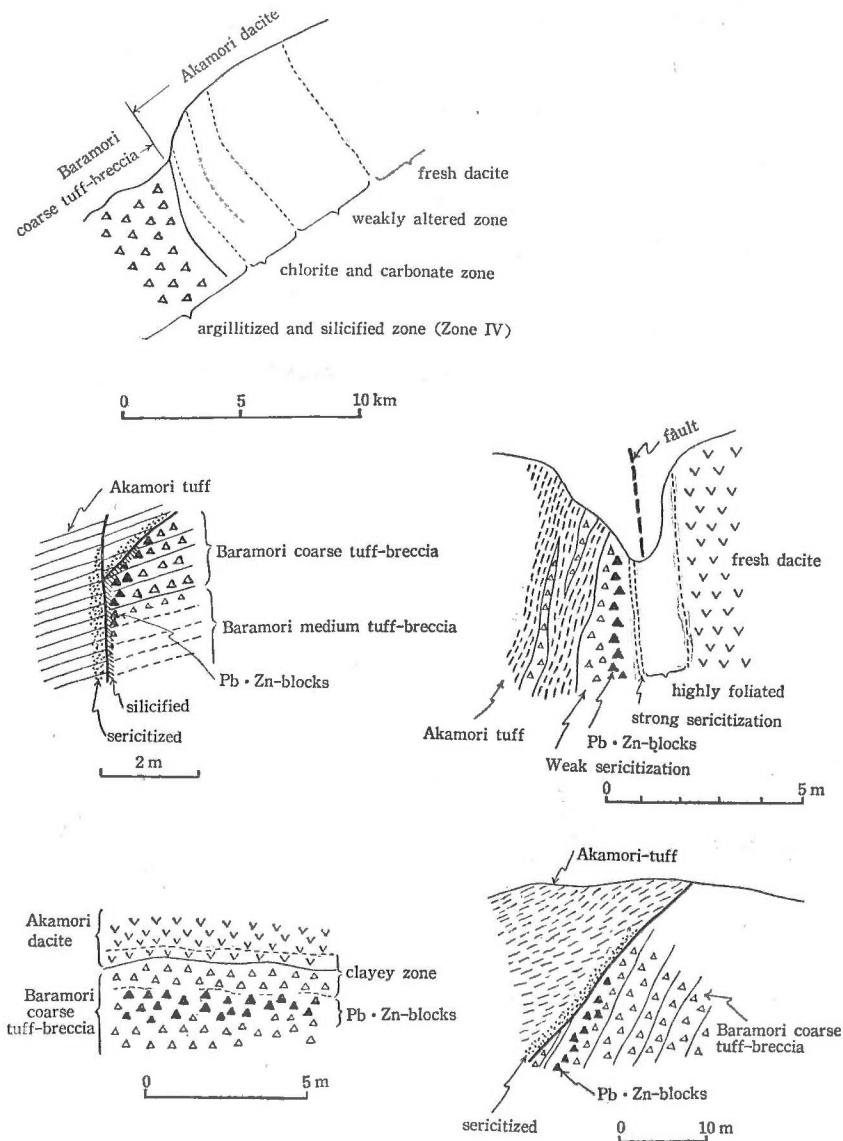


Fig. 2 Several examples showing the mode of occurrence of the lead-zinc ore blocks at the cliff of the open pit (middle and bottom figures), and also of the rock of the chlorite-carbonate zone (top figure)

which in many respects seems to be correlated to the remarkably stratified layers of the Baramori tuff-breccia. Some of the ore blocks, under the close examination, seem to be the metasomatized products in the tuff-breccia, formed by the selective mineralization of ore forming solutions which migrated along the boundary between the tuff-breccia and the Akamori tuff, as well as along the faults which penetrate the tuff-breccia. The previous belief, accordingly, that the ore blocks are the pebbles derived from pre-existing ore bodies elsewhere and deposited on the erosion surface of the Baramori tuff-breccia may be doubtful. (Fig. 2)

3) The Akamori tuff has a clear evidence of being suffered from alteration, for instance, it is disseminated with gypsum, calcite and/or chlorite.

4) The distribution of the bentonite layers of vitric or vitrious lava origin is very extensive and the intensity of the bentonitization is independent to the distribution of the ore deposits.

5) Near the back of the mine office, the grey welded tuff alters into white kaolin clay at about five or ten meters wide, fringed by red peripheral zone of alteration—the aggregates of kaolin, hematite and the relict minerals from the original rocks. Near the base of the welded tuff, thin conglomerate beds are intercalated in which a bulk of metal impregnated pebbles probably derived from the altered wall rocks of the ore deposits are contained. A geologic hiatus is, consequently, of self-evidence, which exists between the metallization and the kaolinization.

II Wall rock alteration

II. 1 General scheme and original rocks

In the Figs. 3,4,5 a compiled map of distribution of the alteration zones with ore deposits, at No. 3 level, a map of wall rock alteration, and a geological map of the open pit are shown, respectively, the data of which are partly due to the

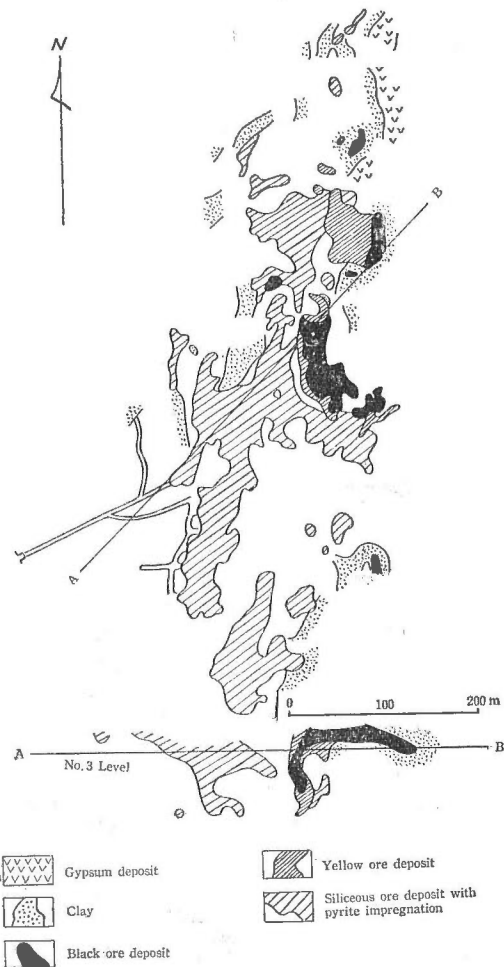


Fig. 3 Distribution of clayey rocks and ore deposits at No. 3 adit level of the Kosaka mine

underground geologic map prepared at the mine. In the Fig. 6, the detailed distribution map of subzones within the silicified zone at No. 3 level, which is newly prepared by the present authors, is presented. The subzoning in the rocks of the silica zone is made preferably based on the grade of silicification and argillization, as follows:



Fig. 4 Map showing the distribution of the altered rocks at the open pit of the Kosaka mine

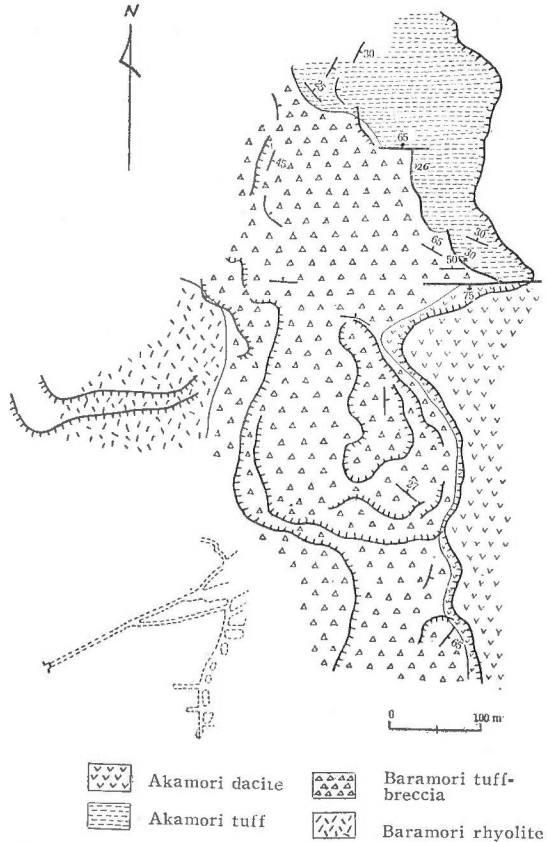


Fig. 5 Geologic map of the open pit of the Kosaka mine

(1) porous silica zone, (2) compact silica zone, (3) moderately silicified zone, and (4) weakly silicified zone. Their petrographic characters are different in appreciable order to the naked eyes, but transitional with each other. In these subzones, the original clastic texture of the rocks is well preserved and the clayey fraction of the rocks, seeing from its chemical composition, is characterized by the distinguished dominance of sericite over chlorite.

With somewhat distinct boundaries and occasionally with slip planes, the silica zone is in contact with the distinguished clayey envelope — the main clayey zone — which is in turn surrounded by fresh rock with gradual transition. The rocks of this transitional zone are also clayey, but it is easily distinguished by the extreme

dominance of chlorite and carbonate, from the rocks of the main clayey zone which is mainly composed of chlorite and sericite.

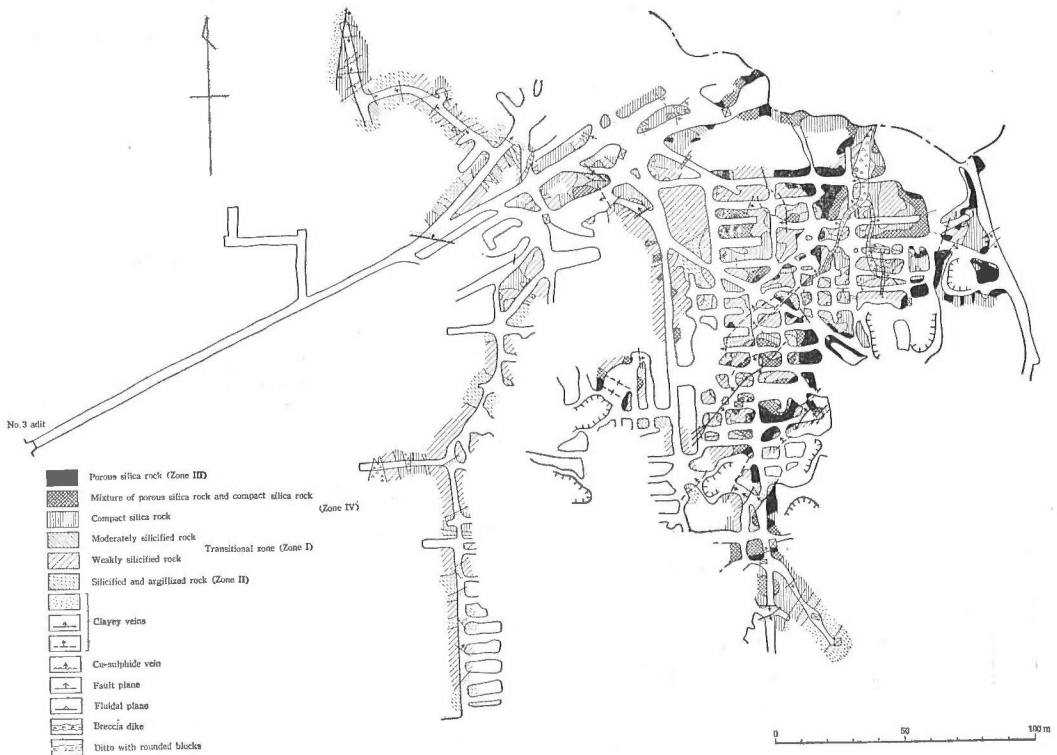


Fig. 6 Distribution map of altered wall rocks in a part of No. 3 level, Motoyama, Kosaka mine (After S. Iwao and F. Kishimoto, 1951)

Irregular veinlets of clay swim in the silica zone, but they never continue to the peripheral clayey zone.

In some other cases, the silica zone shows the gradual transition to the wall rock, or otherwise with obscured clayey zone inserted between.

Pyrite, in appreciable amount, is distributed throughout the silica and clayey zones. And its content in the rocks is roughly proportional to the intensity of silicification of the host rock. For instance, it is highest in the porous silica rock, whereas it decreases toward the outsider, i.e. the less silicified rocks. (Fig. 7) Besides the fine powdery pyrite crystals of uniform dissemination as well as of network veinlets, coarse grained crystals aggregate giving rise occasionally to vein of considerable width or to massive ore bodies in the silicified rocks. In the clayey zone, coarse grained crystals of pyrite are never met with. According to the assays, the content of copper or chalcopyrite, a minor accessory of the pyrite in the silica zone, are shown in gross as increasing in proportion to the pyrite content of the rocks, with local and minor deviations. (Fig. 8)

A number of breccia dikes and pebble dikes strikes $N 20 \sim 40^{\circ} E$, penetrating the

altered rocks, among which four are readily recognized. These dikes graduate on places to the medium or fine grained tuff-breccia dikes and has been called "breccia like dikes". Although they are exceptionally fresh where they cut the "Akamori" tuff, usually altered, together with their wall rocks, suffering from pyrite dissemination, sericitization and chloritization.

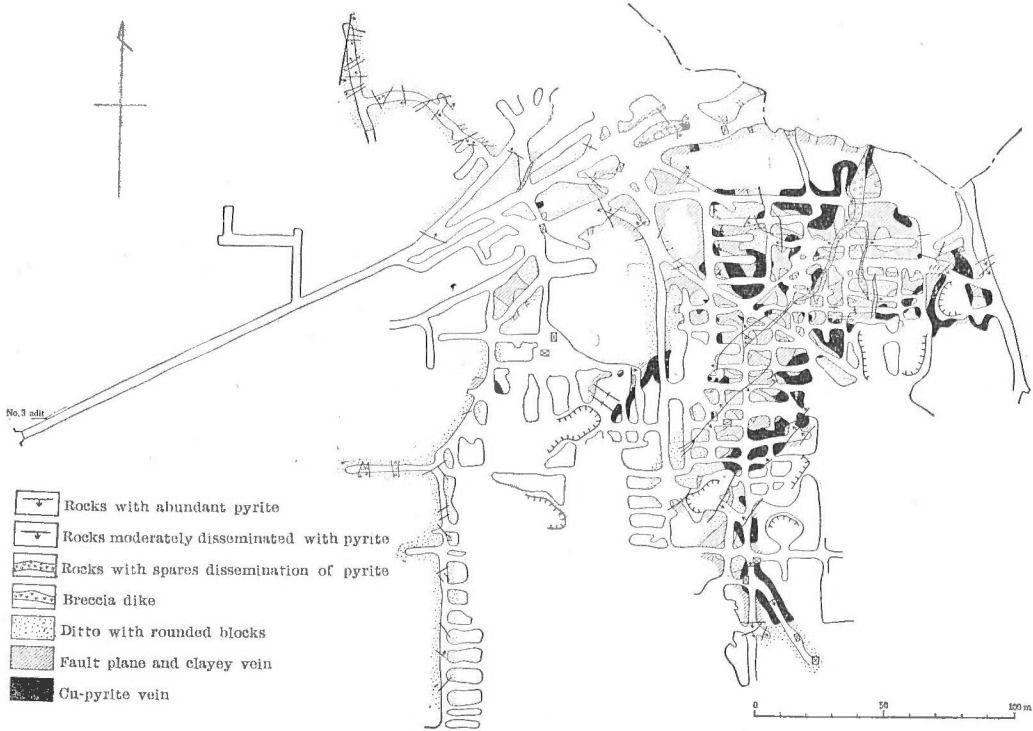


Fig. 7 Distribution map of pyrite in the altered wall rocks in a part of No. 3 level, Motoyama, Kosaka mine (After S. Iwao and F. Kishimoto, 1951)

As to the original rocks of the altered ones, it may be important to notice that the inferred petrographic characters of the fresh "Baramori" tuff-breccia which is now considerably altered and the fresh "Akamori" dacite resemble with each other, both in microscopic texture and chemical composition. Moreover, by eliminating the effect of the cavity filling silica minerals from the silica content of the aphyric dacite, we can find the close resemblance in contents of silica, alumina, ferric oxide, ferrous oxide, and sodium oxide, between the aphyric dacite and the Akamori dacite.

From these instances, it may be safely inferred that Baramori tuff-breccia, Akamori dacite and the aphyric dacite are roughly similar in petrographic characters having dacitic chemical composition. The Akamori tuff-breccia extremely bentonitized, alone belongs to rhyolite.

II. 2 Geologic structure related to the alteration

As to the structural control related to the wall rock alteration, next three subjects

have to keep in mind: (1) cap rock, (2) distribution of the ore deposits in the altered aureole, and (3) breccia dikes and pebble dikes.



Fig. 8 Map showing the distribution of pyritic ore and copper content in the altered rocks at No. 3 adit level (After geologists of Kosaka mine)

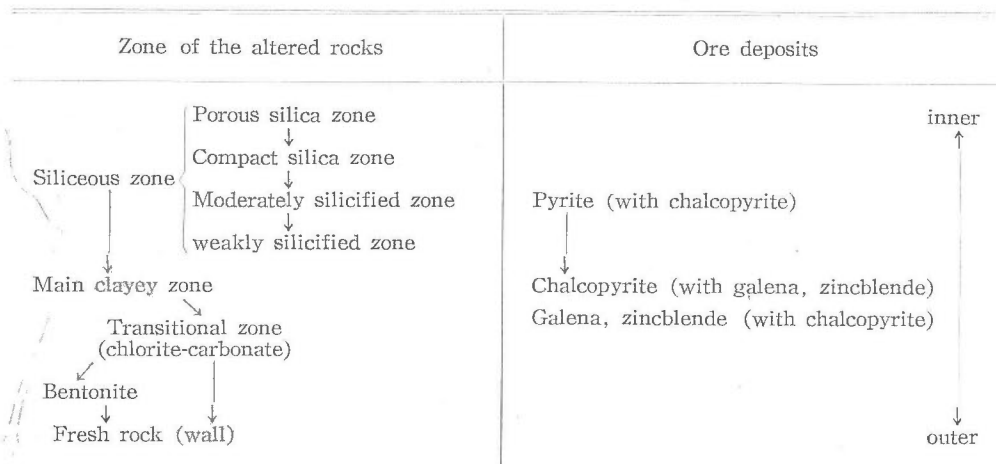
Akamori dacite and Akamori tuff seem to have played a role of the most important cap rock, as described in the preceding pages. From Figs. 6, 7, we can see a rough parallelism of the trend between the altered zones, the distribution of the ore deposits, and also the strike of the breccia or pebble dike swarm. They all strike N 20~30° E direction. This may mean not only the repeated ascent of the solutions along a number of sub-parallel paths striking N 20~30° E, which caused the rock alteration and the ore deposition, but also does mean the re-opening of the fissures which induced the intrusion of the breccia dikes.

II. 3 Zonal distribution of the altered rocks and the sequence of the alteration

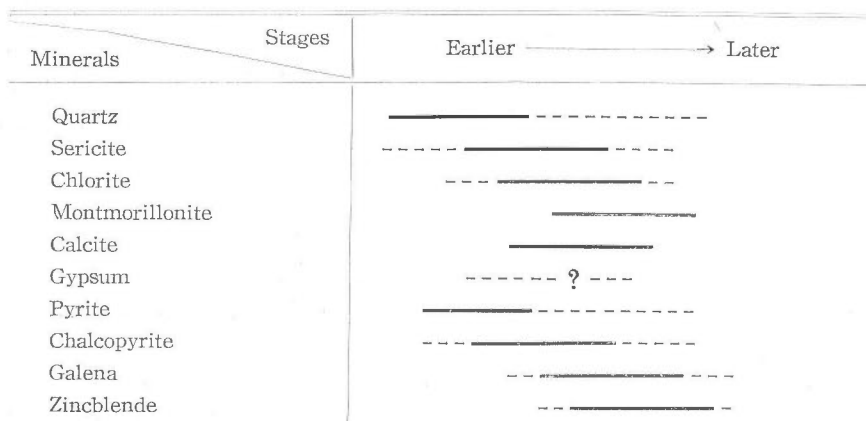
The whole scheme of zonal arrangement of the altered rocks and the associated metal deposits as established are shown in the next.

The next tabulated paragenesis of the altered rocks and the ores is striking, but may not be taken necessarily as showing the two parallel sequences of minerali-

zation, the silicate forming and the metal sulphide deposition.



Because, even a close critical field observations could not reveal the time relation between the silicification and the chlorite-sericite forming. The close similarity in texture between the rocks of the main clayey zones and the silicified zones, both retaining the brecciated texture of the tuff-breccia, makes us feel very difficult to distinguish the time of formation of the two zones. Moreover, there are inserted a thin clayey rock rich in chlorite, between the silicified and the main clayey zone, where the two zones are nearly in contact with each other. This chloritic rock penetrates the main clayey zone, and may be attributed to of later forming than the latter. Penetrating relations show that the pyrite-bearing copper veins and the pyrite veinlets are not earlier than the rocks of the silicified and the main clayey zones, but partly at least somewhat later. A remarkable tendency is the concentration of chlorite along the outermost margin of the altered aureole, giving rise to the zone of chlorite-carbonate. The previously described bentonite which fringes sericite



veins in the marginal zone of alteration may naturally be attributed to the later forming than the sericite. Gypsum, according to the literatures, is mostly restricted to the main clayey zone, but its small fraction is found in the chlorite-carbonate zone as well as in the weakly altered Akamori tuff.

Judging from these evidences above described, migration of the mineralizing solution from conduits into wall rocks, giving rise to the successive zonal arrangement of the altered rocks is more probable than the inward migration or concentration. And accordingly, the paragenesis of silicate and ore minerals is inferred as shown in the above table.

III. Petrography

III. 1 Original rocks

III. 1. 1 Aphyric dacite

Aphyric dacite lava which underlies the Baramori tuff-breccia is partly penetrated by irregular cracks and extremely brecciated, probably at the time of eruption of the Baramori tuff-breccia.

The most fresh rock crops out at the ridge, just east of Yaheidaira. It is dark gray, compact, and somewhat fluidal in texture. In hand specimen, we can recognize a little amount of small phenocrysts of plagioclase, and amygdaloidal cavities of about 1~0.3 cm across which are filled with quartz and opal. (PL. I. Fig. 2)

Microscopic observation reveals the perpathic or phyric, hyalopilitic texture.

Phenocryst: It is made up of andesine, about 2~3%, euhedral, about 1.5 mm long, about 0.5 mm across, very fresh, and shows weak and oscillatory zoning. Albite and Carlsbad twinning is common.

Groundmass: It consists of about equal amount of brown glass and microlites, such as laths of plagioclase, grains of black iron ores, and some other mafic minerals. The andesine laths are about 0.2 mm long, clear, showing oscillatory zoning. Albite-Carlsbad twinning is common. Microphenocrysts of oligoclase are about 0.1~0.05 mm in length, fresh and assume Albite twin.

The chemical composition of the rock is given in the Table 1, in which the abnormally high content of silica is due to the amygdaloidal opal and quartz, as already pointed out. The calculation with revision of silica percent, therefore, gives the similar values to the Akamori dacite.

III. 1. 2 Akamori porphyritic dacite

It is dark greenish grey, massive, hard, and porphyritic due to phenocrysts of quartz and plagioclase. Chloritization, albitization, sericitization and carbonatization are the very common type of alteration. The original texture of the rock is well retained. (PL. II. Fig. 3)

Phenocrysts: They occupy about 35~40% of the rock, among which plagioclase is dominant. Quartz, about 1~2 mm in diameter, is often partly corroded. Labra-

chlorite and andesine occur as thick tabular, euhedral or subhedral crystals, about 2~3 mm long. They are mostly speckled with chlorite or sericite aggregates growing on cleavage or cracks. Albite replaces either partly or completely the host plagioclase crystals along their cleavages. Mafic phenocrysts are subhedral, long prismatic, about 1~2 mm long and completely replaced by fine mixture of chlorite, sericite and black opaque iron ores.

Table 1. Chemical compositions and specific gravities of dacite and dacitic rocks

wt%	I-2	II-2	III-2	IV-2	11-2	136-2	203-2	205-2	206-2	256-2	257-2
SiO ₂	81.44	70.98	82.82	70.02	41.42	79.72	64.50	60.78	70.78	65.28	76.55
TiO ₂	0.21	0.31	0.17	0.23	0.42	0.27	0.54	0.46	0.48	0.13	0.31
Al ₂ O ₃	5.10	10.50	1.87	6.03	31.31	8.54	14.29	12.59	13.77	10.80	12.40
Fe ₂ O ₃	0.09	0.52	0.02	0.27	0.25	0.26	1.44	0.11	0.17	1.23	1.17
FeO	0.13	0.21	0.21	0.26	0.93	0.18	2.97	3.07	0.24	0.06	0.26
Fe	4.16	4.35	5.85	8.76	0.65	2.21	0.03	0.10	2.46	0.03	0.03
MnO	0	0	0	0	0.03	0	0.14	0.21	0	0.01	0.03
MgO	0.34	0.53	0.11	0.31	9.45	0.35	2.15	4.84	0.97	2.67	0.14
CaO	0.02	0.03	0.02	0.04	0.27	0.07	3.51	4.81	0.23	1.23	1.81
Na ₂ O	0.06	0.07	0.05	0.08	0.06	0.09	2.21	1.56	1.48	0.27	3.43
K ₂ O	1.15	2.50	0.38	1.55	6.02	1.88	1.60	1.02	0.94	0.24	1.63
+H ₂ O	1.29	2.69	0.72	1.45	7.52	2.36	3.92	3.85	4.20	6.51	1.34
-H ₂ O	0.28	0.85	0.24	0.26	0.61	0.47	0.47	0.84	1.17	11.33	0.66
P ₂ O ₅	0.06	0.01	0.01	0.01	0.19	0.01	0.12	0.10	0.07	0.01	0.01
S	4.78	4.99	6.72	10.06	0.75	2.54	0.04	0.12	2.83	0.04	0.04
SO ₃	0.61	1.18	0.57	0.55	0	0.94	0	0	0.07	0	0
CO ₂	—	—	—	—	—	—	1.88	5.32	—	0	0
Total	99.72	99.72	99.76	99.88	99.88	99.89	99.81	99.78	99.86	99.84	99.81
G ₁	3.10		2.72	2.94	2.77		2.71	2.72	2.74		
G ₂	2.73		2.34	2.69	1.95		2.55	2.53	2.50		

(Analyst: K. Maeda) G₁: Sp. Gr. G₂: apparent Sp. Gr.

I-2: mixed sample of moderately silicified dacite (Zone I)

II-2: ditto of weakly silicified and argillized dacite (Zone II)

III-2: ditto of porous silica rock (Zone III)

IV-2: ditto of compact silica rock (Zone IV)

11-2: white sericite-chlorite clay of main clayey zone.

136-2: moderately silicified dacite, no. 136.

203-2: slightly altered Akamori dacite, no. 203.

205-2: moderately altered Akamori dacite, no. 205.

206-2: highly altered Akamori dacite, no. 206.

256-2: bentonitic clay from Shibusawa, no. 256.

257-2: fresh aphyric dacite, no. 257.

Groundmass: It is made up of minute crystals of quartz 60~70 %, plagioclase 10~15% and accessories 20~30 %. They are about 0.1~0.03 mm in size. Plagioclase laths suffer albitization by halves. Chlorite and sericite flakes intermix with each other and fill up the interstices of plagioclase. Calcite, titanite and a small amount of pyrite are scattered throughout the groundmass.

It is not clear whether the appearance of pyrite, calcite, chlorite and sericite in the rock means the alteration in direct connection with the ore forming.

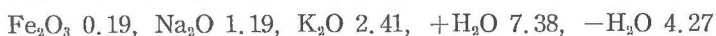
The chemical composition of the rock, on eliminating the effect of carbonatization and chloritization, is like the aphyric dacite minus amygdaloidal silica minerals. (Table. 1)

III. 1. 3 Vitreous dacite flow partly altered into bentonite.

The rock is characterized by emerald colour, dense but somewhat brittle. Under the microscope, it consists of spherulites of chalcedonic quartz, fresh andesine, fresh glass fragments and bentonitic minerals. (PL. I. Fig. 1)

The spherulites are about 0.1~0.5 mm in diameter and occupy about 20% of the rock. Andesine is about 1~2 mm long, shows weak and oscillatory zoning and twinning after Albite and Carlsbad laws. It is usually crushed and filled by vitreous matter along the cracks. Bentonitic part, seeing from its wavy elongated outline, may be inferred to be an alteration product of semi-solidified vitric fragments. Angular fragments of clear glass, however, which is remarkably fresh may have had erupted presumably as a solidified glass, together with the other phenocrysts.

The partial chemical composition is as follows:



A considerable amount of alkalis is characteristic, compared with typical bentonite. (Table. 1)

III. 2 Altered rocks of chlorite-carbonate zone

III. 2. 1 Weakly altered Akamori porphyritic dacite, no. 203.

It assumes somewhat pale green and soft, due to weak alteration but retains its original texture in detail.

Phenocrystic quartz suffers no recrystallization, and remains fresh. Phenocrystic plagioclase is mostly replaced by mixture of chlorite, carbonate and sericite, but a few other is replaced by albite with loss of zonal structure. (PL. II. Fig. 4)

In groundmass, filling up the interstices of albitized feldspar laths and recrystallized quartz, chlorite, sericite, calcite and quartz are predominant. Groundmass is also penetrated by quartz and calcite-veinlets. Somewhat rounded pyrite cube, grains of titanite, leucoxene and black iron ore are scattered throughout. The chemical composition is shown in the Table 1.

III. 2. 2 Moderately altered Akamori porphyritic dacite no. 205

Although the original texture is well preserved, silicification, chloritization and carbonatization are strong.

Phenocrystic quartz is going to recrystallize from the crystal surface into an aggregates of wedge shaped quartz. Phenocrystic feldspar is mostly replaced by chlorite aggregates or by carbonate aggregates. But, some individuals are replaced either by albite or by the aggregates of minute sericite flakes of less than 0.005 mm

long. Mafic phenocrysts are entirely replaced by mixture of carbonate, chlorite and black iron ores.

The feature of alteration of the groundmass is almost similar to the specimen no. 203, except a greater amount of chlorite, sericite and secondary wedge shaped quartz.

The chemical composition of the rock clearly shows the marked predominance of chlorite and carbonate. (Table 1)

III. 2. 3 Highly altered Akamori porphyritic dacite, no. 206

In the rock, quartz, albitized plagioclase and sericite substitute for chlorite and carbonate. The rock is rather soft, but porphyritic texture of the original rock is still well preserved.

There are two kinds of porphyritic quartz, one is the relic of phenocryst, and another is the secondary quartz. Plagioclase phenocryst is mostly suffered albitization, with its remainder replaced by aggregates of sericite flakes.

About 20~30% of the groundmass is albitized plagioclase laths, 40~50% fine quartz aggregates, and the remainder is sericite flakes of 0.01 mm size.

Wedge shaped quartz crystals of about 0.3 mm long, cubic pyrite of 0.1~0.2 mm size and grains of rutile are universal.

The chemical composition is shown in the Table 1.

III. 3 Altered rocks of silicified zone

III. 3. 1 Weakly silicified and argillized dacite no. 131 (Zone II)

The rock is completely replaced by quartz and sericite, with subordinate amount of chlorite, but retains its original texture nearly unobliterated. (PL. III. Fig. 5)

Phenocrystic feldspar occupies about 10~15% of the rock. It is euhedral, 1~1.5 mm long, almost completely replaced by spherulitic and interstitial aggregates of sericite.

The groundmass is made up of fine grained aggregates of quartz about 0.05 mm in diameter, and sericite aggregates after the groundmass feldspar.

Pyrite crystals, occupying about one percent of the rock and the dusty aggregates of titanite grains about 0.001~0.003 mm across are scattered. Wedge shaped quartz gives rise occasionally to veinlets and/or to pools. Angular breccia which is largely replaced by sericite, and slaty fragments stained by sericite and carbonate matters are not rare in the rock. Chlorite, which is not recognized under the optical microscope, is proved to be associated with sericite in smaller amount by chemical and X-ray analysis.

One of the characteristic features of the rock is the gross size of the phenocrystic feldspar. It is far larger than that in the aphyric dacite and resembles to Akamori dacite.

III. 3. 2 Moderately silicified rock with a few sericite flakes, no. 136 (Zone I)

The rock is more strongly silicified than the rocks above described, but its texture

still follows its original one. (PL. IV. Fig. 7)

Phenocrystic quartz, corroded, about 0.5~1 mm in diameter, occupies about 3~5% of the rock. Phenocrystic feldspar, about 0.5~1 mm long, is replaced by subparallel aggregates of sericite flakes mixed with quartz grains of 0.1 mm size. Captured fragments of slate are found in the similar manner as in the rocks above mentioned. Pumice fragments are partly altered to aggregates of sericite flakes of 0.05 mm long.

The abundance of quartz veinlets and pockets is particularly remarkable. The veinlets are composed of coarse prismatic quartz and fine grained aggregates of quartz.

The chemical composition is listed in the Table 1.

III. 3. 3. Compact silica rock, no. 177 (Zone IV)

The rock is dominantly composed of quartz-grains, very hard and dense, with moderately obliterated and brecciated feature of the original rock. Under the microscope, however, the porphyritic texture of the original rock is recognized to a considerable degree. (PL. III. Fig. 6)

The texture of the rock, thereby, depends dominantly upon the heterogeneity of silicification. The rock is made up of the finest grained part (0.02~0.002 mm in grain size) in which the texture of the original rock is somewhat retained, the coarse grained part (1~0.2 mm in grain size) in which the original texture is completely destroyed, and the transitional part, respectively. The coarse grained fraction suffering strong silicification, is composed of bulk of quartz veinlets and pods. In the medium grained transitional part, filling the interstices of quartz grains, small detached subparallel flakes of sericite are gathered on places into pseudomorphs after sporadic feldspars. Pyrite crystals and small clots of titanite aggregates are very common. A considerable abundance of pyrite is characteristic, as presented in Table 1.

The chemical composition of the rock is shown in the same Table.

III. 3. 4 Porous silica rock, no. 66 (Zone III)

The rock is considerably porous, mostly composed of quartz grains, and associated with pyrite crystals as well as an extremely small amount of sericite flakes. The detail of the original texture is, of course, completely destroyed. (PL. IV. Fig. 8)

The rock is usually very pure, white, or pale gray, but occasionally it is yellowish brown stained by limonite. In hand specimen, it assumes breccia like structure, caused by the random intermixing of the coarse, intermediate, and fine grained parts.

In the coarse grained part, small drusy cavities occupy about 10~15% of the rock in volume, and wedge shaped quartz, about 1 mm long, is absolutely dominant.

Sericite is very rare, less than about 0.5% of the rock, and occurs as very minute flakes. Fine pyrite cube, about 0.4~0.1 mm across, is rather common.

III. 4 Clay

The clay of the main clayey zone is nearly white or otherwise pale grayish

green, and well retains, under the close observation, the breccia like structure of the original rock. Along the fault zone in the clay, however, many parallel slip planes and foliations are dominant.

Table 2. The chemical compositions and average refractive indices of the clay (Analyst: K. Maeda)

	No. 11 (white)	No. 13 (green)		No. 11 (white)	No. 13 (green)
SiO ₂	41.42	38.66	Na ₂ O	0.06	0.12
TiO ₂	0.42	0.38	K ₂ O	6.02	3.82
Al ₂ O ₃	31.31	27.22	+H ₂ O	7.52	8.19
Fe ₂ O ₃	0.25	1.09	-H ₂ O	0.61	1.02
FeO	0.93	2.52	P ₂ O ₅	0.19	0.04
Fe	0.65	1.55	S	0.75	1.78
MnO	0.03	0.07	SO ₂	—	0.02
MgO	9.45	13.35	CO ₂	—	—
CaO	0.27	0.06	Total	99.88	99.89
				$\gamma=1.582$	$\gamma=1.580$
				$\alpha=1.544$	$\alpha=1.558$

Table 3. X-ray powder photograph of the clay

No. 11 (white)			No. 13 (green)			No. 11 (white)			No. 13 (green)		
I	d		I	d		I	d		I	d	
10	10.0	s	5	10.0	s	2	2.20		1	2.02	s
10	7.10	ch	8	7.09	ch	3	2.13		7	1.996	ch, s
7	4.99	s	2	4.99	s	10	1.996	s, ch	1	1.91	
7	4.73	ch	4	4.72	ch	1	1.873		2	1.88	ch, s
7	4.46	s	4	4.46	s	1	1.818		2b	1.82	
0.5	4.14		1	4.12		1	1.726			1.81	
1	3.89		1	3.90		0.5	1.692		3	1.73	
1	3.70		1	3.70	s	3	1.65		1	1.69	
10	3.55	ch	10	3.54	ch, s		1.64		2	1.66	
10	3.32	s	6	3.32	s	3	1.558		2	1.63	
1	3.19		1	2.97		3	1.532	ch	4	1.560	ch
1	2.98		4	2.83	ch	7	1.496	s	4	1.533	ch
6	2.86		7b	2.58		1	1.390		4	1.498	s
	2.83			2.53		1	1.352		2	1.389	ch
10	2.58		5	2.43	ch, s		1.338		1	1.346	
	2.55		5	2.37	s	1	1.294		1	1.331	
2	2.44		3	2.25	ch		1.286		1	1.291	
4	2.375		3	2.20	s	1	1.246		1	1.265	
2	2.246		2	2.13	s	0.5	1.219		1	1.243	

s : sericite

ch : chlorite

Under the optical microscope, both white and pale grayish green clay seem monomineralic, composed of minute flakes of equally sericitic appearance and non-pleochroic. A slight difference in refractive indices, with respect to colours are recognized; $\alpha=1.554$, $\gamma=1.582$ for the white clay, and $\alpha=1.558$, $\gamma=1.580$ for the pale grayish green clay, respectively. Electron microscope could'nt, however, discriminate the difference of the two.

This clay is, then, conformed to be a mixture of sericite and Mg-chlorite by X-ray, chemical, as well as by differential thermal analysis as given in the tables and figure. (Tables. 2, 3, Fig. 9)

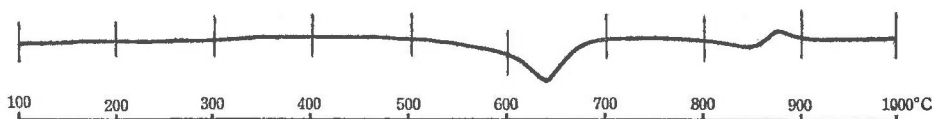


Fig. 9 Differential thermograph of the clay from the principal clayey zone

Seeing from the considerable variance in the ratio of K_2O to MgO , the ratio of sericite seems to be variable.

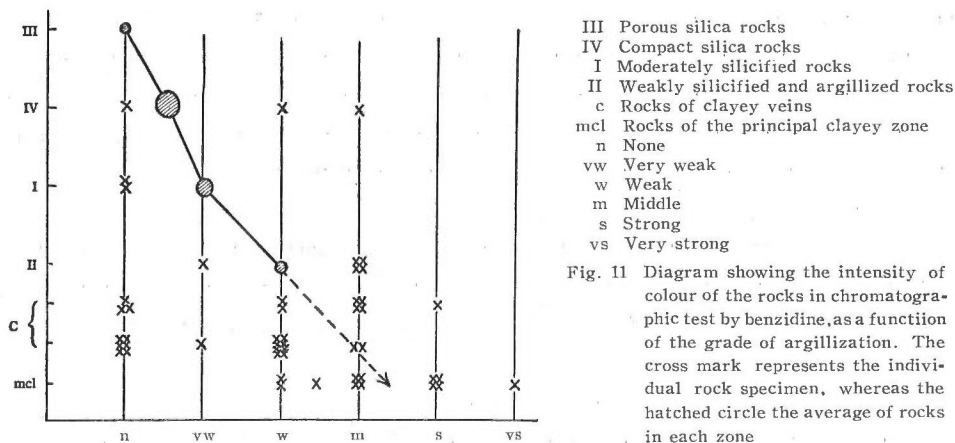
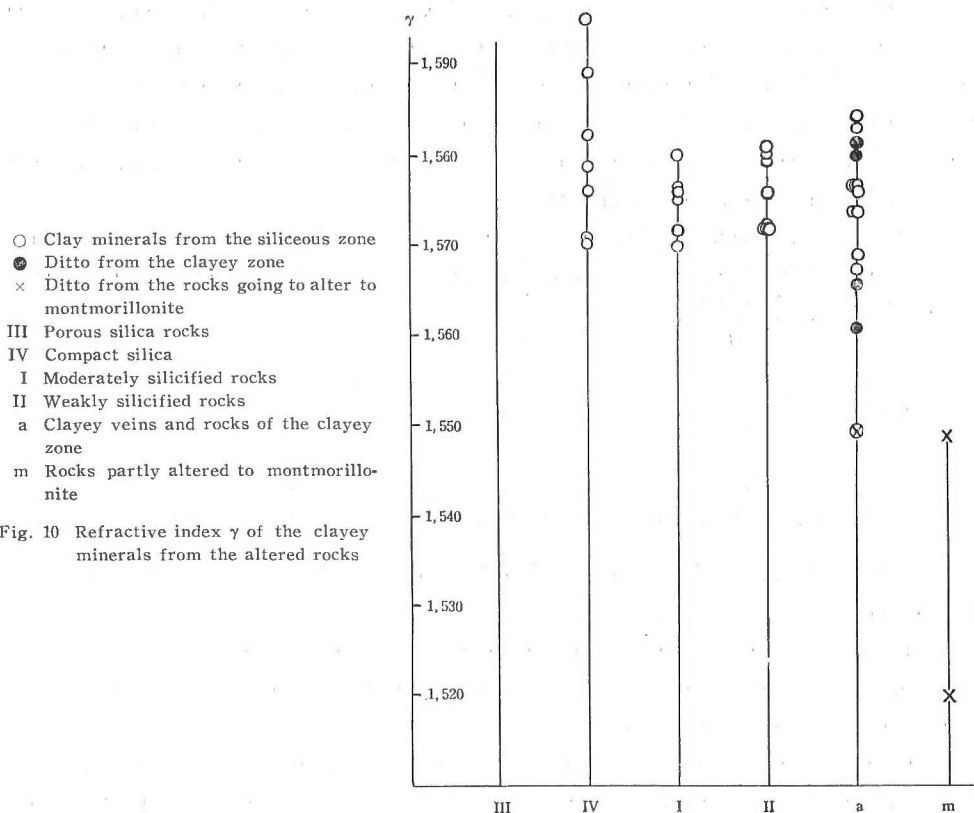
The rocks of the silicified zone are generally higher in the ratio of K_2O to MgO than the main clayey zone. This may mean the less content of chlorite compared to sericite than the clayey zone.

The refractive indices γ of the clay minerals from each rock specimen of the silicified zone and from each of the clayey zone show no remarkable variance as measured, which is referable to the ratio of sericite to chlorite. The value of γ seems, therefore, rather to vary according to the difference in characters of chlorite as well as of sericite. From these considerations, we can naturally see the increase in variance of characters of the clay minerals therein contained, from the center of alteration of earlier forming to the peripheric zone of later forming. The extremely low value of γ for the clay of branched veins means an intermixing of montmorillonite. (Fig. 10)

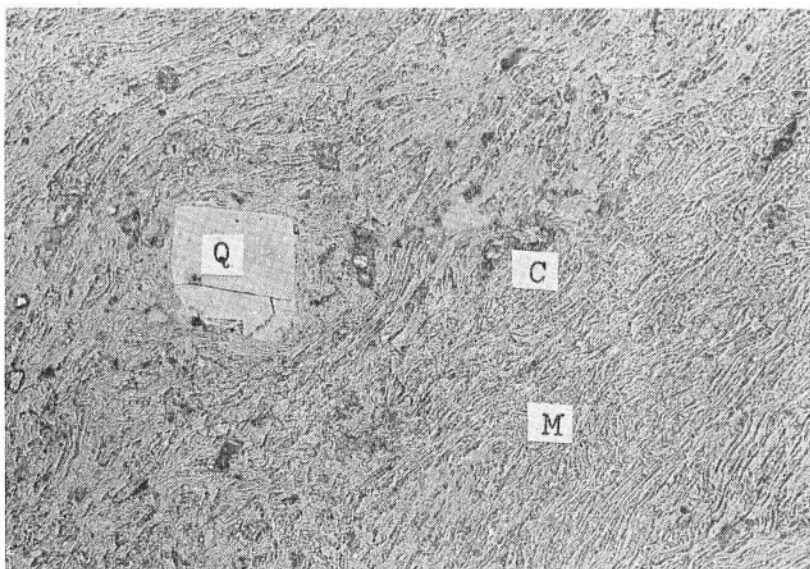
A chromatographic test by benzidine was also performed for 14~25 specimens collected from the altered zones, but no more distinguished results were obtained, than to indicate a rough intensity of argillization for each rock specimen. (Fig. 11)

III. 5 Weakly altered Akamori tuff, no. 4

The rock is a kind of the altered coarse vitric crystal tuff of rhyolite and similar in field appearance to the so-called Oyaishi in the north Kwantō region. It assumes fluidal or stratified texture due to the sub-parallel orientation of green patches which are about 1~0.5 cm long, and sporadically scattered in the porous white matrix. The patch may be of vitric pumice origin, just corresponded to the so-called "Miso" of the Oyaishi.



Under the microscope, the matrix consists principally of aggregates of fine grained quartz, about 0.05 mm across and is associated with a few patches of chlorite. The green patch which possesses by halves the rock in volume, is made up of a fine mixture of fresh glass and montmorillonite, by which arrangement the original texture of pumice is well retained. (Fig. 12)



Q : Quartz phenocryst C : Carbonate rimmed by chlorite
M : Vitric glass and montmorillonitic minerals

Fig. 12 Weakly altered Akamori tuff (no. 4), showing vitric texture
polarizer only, $\times 21$

A few phenocrysts of quartz and oligoclase are recognized. Quartz is euhedral pyramidal or subhedral, 2~0.5 mm in length, fringed by fine grained aggregates of secondary quartz and possesses about 7~8% of the rock. Oligoclase is generally fresh and partly replaced by chlorite. It is very scarce in amount.

In some specimens collected from the cap rock exposing on the southwestern slope of the open pit, we can recognize microscopically the crystals of calcite and gypsum, both rimmed by chlorite aggregates. They do not exceed three percent of the rock.

III, 6 Breccia dikes and pebble dikes

As previously mentioned, the rock is full of many rock fragments of slate, cherty slate, rhyolite, and sometimes of granite porphyry. They are about 3 cm in average diameter, and 20 cm in maximum, either angular, or rounded in shape.

These fragments are suffered usually from sericitization, silicification, carbonatization and also weak chloritization. Very frequently, however, the matrix is more strongly altered, giving rise to soft cementing materials.

IV. Chemical composition of the altered rocks

The abundance of the principal elements in the rocks of each altered zone as calculated on basis of $O=160$, taking also porosity into consideration, is given in the following table. (Table. 4)

The method of this calculation is preferred merely for conventional purpose to get the ratio of elements in unit volume of the rock. The abundance of the minor

Table 4. Calculated number of cations in the analysed rocks, on basis of O=160, and also taking the porosity into calculation

O=160	I-2	II-2	III-2	IV-2	11-2	203-2	205-2	206-2	257-2
Si	59.5	55.6	61.0	58.1	23.3	55.4	50.4	53.0	61.2
Ti	0.14	0.22	0.08	0.15	0.18	0.33	0.27	0.26	0.2
Al	4.3	9.7	1.7	5.9	20.4	14.3	12.4	12.1	11.7
Fe	6.7	0.1	4.7	8.1	1.8	2.9	2.3	2.1	0.95
Mn	0	0	0	0	0	0.1	0.15	0	0
Mg	0.33	6.0	0.14	0.37	10.01	2.7	6.0	1.1	0.2
Ca	0	0	0	0	0.2	3.2	4.3	0.2	1.6
Na	0.84	0.77	0.08	0.22	0.12	3.5	2.5	2.1	5.3
K	1.1	2.6	0.32	1.6	3.7	1.7	1.1	0.97	1.7
H	3.9	7.4	2.3	4.7	16.9	12.5	13.4	13.4	5.2
P	0.08	0	0	0	0	0.1	0.9	0.07	0
S	6.5	7.6	9.3	15.5	1.4	0	0.16	4.0	0

elements determined by spectrochemical method is also tabulated. (Table 5)

V. Considerations

V. 1 Loss and gain of elements during the alteration

It is difficult and impossible to reveal the actual feature of migration of elements in the altered rocks, from chemical composition alone. Because, an altered rock with equal silica percent to its original rock, for instance, may never mean generally the evidence of freezing of silica in its original position during the course of alteration.

Can we then not usually see the most probable scheme of moving of elements contained in the original rocks during alteration? There may be several cases in which we can do.

The evidences such as maintenance of constant volume during alteration, increase in porosity due to subtraction of elements,^{3),8)} marked concentration of some elements which are extremely poor in the adjacent zone of alteration compared with its original rock, and the combination of them may be all fortunate to the recognition.

In the present case of the Kosaka mine, there are no evidences of volume change during the alteration. Porous silica rocks at the center of alteration as already mentioned, and the extreme enrichment of several elements in the adjacent zone which is very poor in those elements are also characteristic.

Keeping all these evidences in mind, and comparing the chemical composition of the altered rocks to the fresh dacitic rocks, we can establish a most probable general scheme of addition and subtraction of elements to or from the original rocks in the process of the alteration.

In Figs. 13, 14, 15, and 16 are presented the variation diagram of elements in the altered rocks.

V. 1. 1 Chlorite-carbonate zone (256~206)

An approximate persistency in abundance of Si and Al shows the less progressed

Table 5. Spectrographic composition in weight percent.
(Analyst: K. Takahashi)

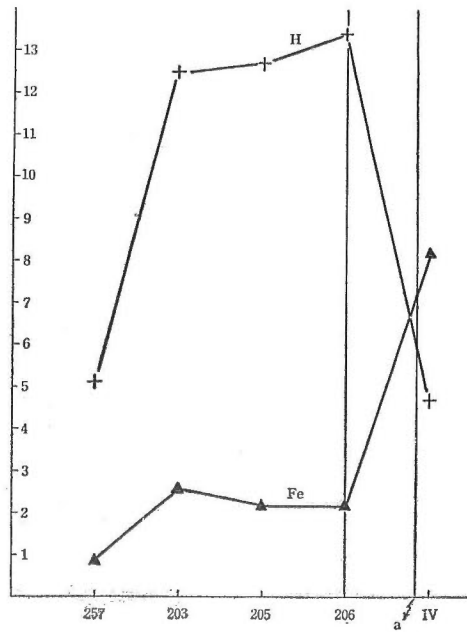
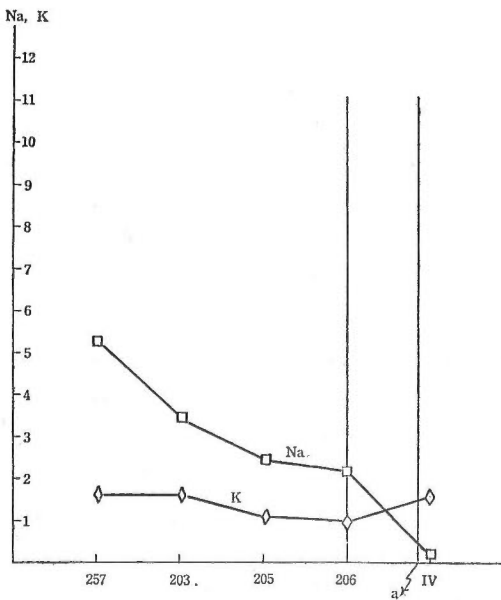
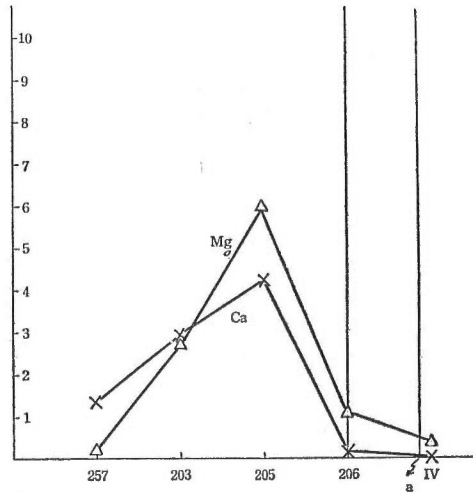
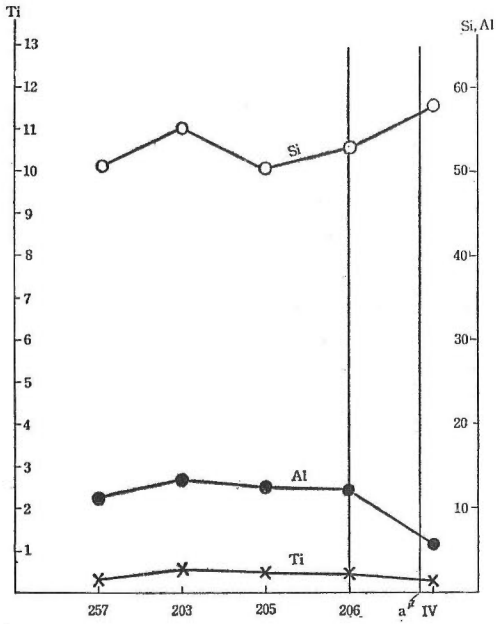
wt%	Rb	Li	Cs	Ba	Sr	Cr	Co	Ni	Zr	Mn	V	Ga	Ag	Cu	Zn	Pb	As	Ge
I-2	0.005	<0.001	—	0.003	—	—	—	—	0.002	0.001	—	0.001 _s	0.003	0.007 _s	0.01	0.005	—	—
II-2	0.007 _s	0.001	—	0.02	—	—	—	—	0.003	0.002	—	0.002	0.005	0.005	<0.01	0.005	—	—
III-2	0.002 _s	—	—	0.01	—	—	—	—	0.001	<0.001	—	<0.001	0.005	0.005	<0.01	0.005	—	—
IV-2	0.012 _s	0.003	—	0.05	0.001	—	—	—	0.001	0.002	—	0.001	0.007 _s	0.005	0.01	0.005	<0.01	—
11-2	0.003	0.003	—	0.02	0.005	—	—	0.001	0.002	0.02	0.002	0.008	—	<0.001	—	—	—	—
13-2	0.001	0.001	—	0.01	0.007 _s	—	—	0.001	0.001	0.015	0.002	0.007	—	<0.001	—	—	—	—
197	0.015	0.007	—	0.01	0.02	0.001	—	—	0.004	0.07	0.004	0.004	—	0.001	—	0.005	—	—
203-2	0.015	0.005	—	0.01	0.02	<0.001	—	—	0.002	0.10	0.008	0.004	—	<0.001	—	0.002 _s	—	—
204-2	0.010	0.010	—	0.04	0.015	—	—	—	0.003	0.18	0.008	0.003	—	<0.001	0.01 _s	—	—	—
205-2	0.007 _s	0.007	—	0.02	0.015	—	—	—	0.004	0.15	0.004	0.003	—	<0.001	0.02 _s	—	—	—
206-2	0.007 _s	0.002	—	0.01	0.005	—	—	—	0.004	0.004	0.004	0.003	0.002	0.001	0.01 _s	0.002 _s	—	—
257-2	0.015	0.003	—	0.005	0.01	0.001	—	—	0.01	0.02	0.001	0.003	—	<0.001	—	0.002 _s	—	—
218	0.001	0.001	—	0.002	0.01	—	—	<0.0005	0.002	0.007	0.001	0.003	—	<0.001	<0.01	—	—	—

I-2, II-2, III-2, IV-2, 11-2, 203-2, 204-2, 205-2, 206-2, and 257-2 are the specimen numbers cited in Table 4.

13-2: pale green sericite-chlorite clay of main clayey zone.

197: weakly altered Akamori porphyritic dacite, no. 197.

218: bentonitic clay, no. 218.



257 Fresh aphyric dacite

203 Weakly altered Akamori porphyritic dacite

205 Moderately altered Akamori porphyritic dacite

a Average of silicified rocks and the rocks of the principal clayey zone

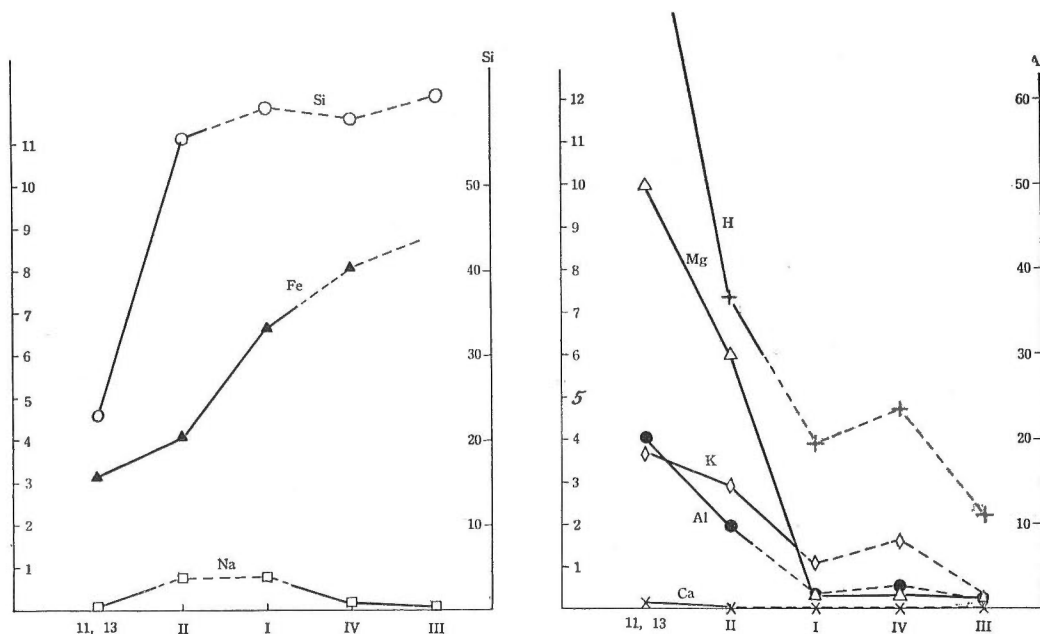
IV Compact silica rock

203 Weakly altered Akamori porphyritic dacite

206 Highly altered Akamori porphyritic dacite

a Average of silicified rocks and the rocks of the principal clayey zone

Fig. 13 Diagram showing the variation in abundance of elements in the chlorite-carbonate zone (calculated as O=160)



11,13 Rocks of the principal clayey zone
 II Weakly silicified and argillized rock (no. 131)
 I Moderately silicified rock with a few sericite flakes (no. 136)
 IV Compact silica rock (no. 177)
 III Porous silica rock (no. 66)
 Fig. 14 Diagram showing the variation in abundance of elements in the silicified and principal clayey zones (calculated as O=160)

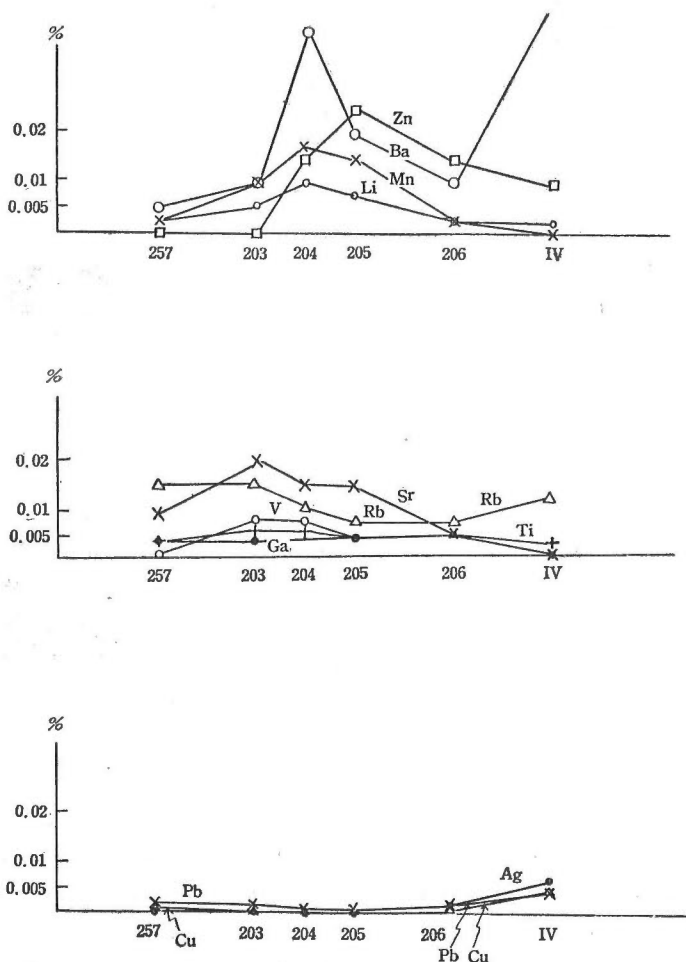
stage of alteration. In the more strongly altered rocks constituting the inner part of the altered aureole, a great variance in abundance of Si and Al is usual. The loss of Na and K is caused by the leaching of feldspar and glass.

Sericite flakes which are newly produced seem to be not sufficient in amount to exhaust the total potash of the original rocks. The increase of H and Mg means the dominance of chlorite, whereas the increase of Ca means the growth of secondary calcite.

It is noteworthy that, among trace elements, Zn alone concentrates markedly in the rocks, while others such as Ag, Cu, and Pb show no tendency to concentrate. The gain of Fe represents the impregnation of pyrite grains.

V. 1. 2 Silicified and clayey zones

The inferred mean chemical composition of the rocks is characteristic in showing a slight gain of Si and K, a considerable increase of Fe, S, a slight loss of Al, a remarkable loss of Na, H, Mg, Ca as compared to the chlorite-carbonate zone. Among the trace elements, Ba, Rb, Ag, Pb, and Cu increase, and Sn, Mn, V, Zn and Li decrease. The increase of K is represented by the development of clayey zone, the increase of Si by the silicified zone, and the loss of Mg and Ca by the



257 : Fresh aphyric dacite 203, 204, 205 : Rocks of the chlorite-carbonate zone
 206 : Weakly sericitized rock IV : Rocks of the outer part of the silicified zone

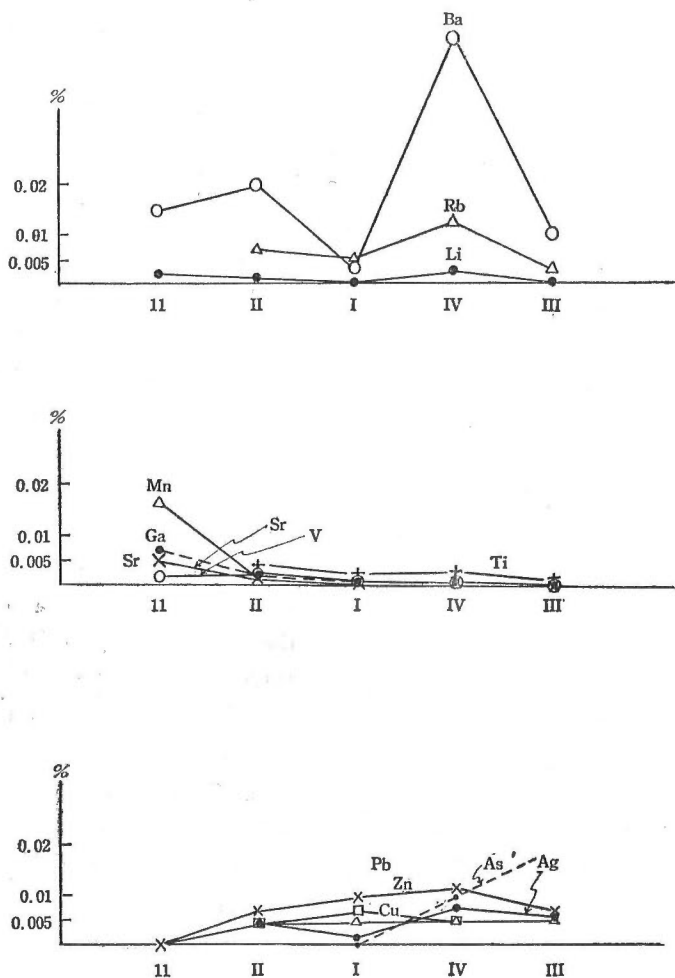
Fig. 15 Diagram showing the variation in abundance of minor elements in the outer zone of the altered aureole

diminishing in amount of chlorite and calcite.

V. 1. 3 Addition and subtraction of elements as a whole

From the variation in abundance of elements in the each zone of alteration, we can establish a general scheme of loss and gain of the constituents in the altered zones as a whole. That is:

- 1) Elements added evidently from outside by ascending ore forming fluid, are Fe, H, Ba, C, Ag, Cu, Zn, Pb and S.
- 2) Elements removed from the altered zones are Na, Rb, Sr, Li and a part of Ca.
- 3) Elements which may be of dispute whether they were contained in the original



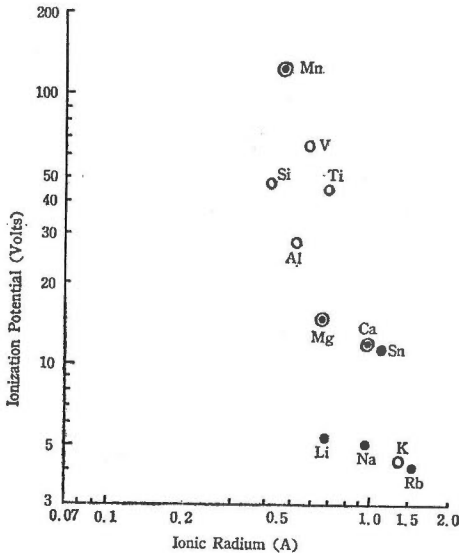
II: Rocks of the principal clayey zone
 II, I, IV: Rocks of the outer part of the silicified zone
 III: Porous silica rock, the core of the silicified zone
 Fig. 16 Diagram showing the variation in abundance of minor elements in the altered rocks

rocks at the equal ratio in abundance to the altered rocks or not, are Al, Mg, K, Mn, V, Si and Ti. Of these elements, however, Al, K, Mn, V, and Ca migrate to appreciable distance within the altered zones. Si and Ti show lower degree of migration.

The elements may be arranged, thereby, in decreasing order of difficulty of migration during the course of the alteration, as follows:

Ti, Si > Al, K, Mn, V > Mg, Ca > Na, Rb, Sr, Li, (Ca)

The fact that, with exception of the two elements, K and Mn, this order coincides roughly with that of ionization potential, may effectively suggest the hydrous nature of the alteration agent and consequently the importance of pH of the solution in giving the zonal distribution of the altered rocks. Fig. 17 shows this order of



- Elements which are entirely removed
- ⊙ Elements which are concentrated in the outer zone of the altered aureole
- Elements which are mostly remained in the core of the altered aureole

Fig. 17 Diagram showing the distribution of the moved elements in the altered aureole with respects to ionic radius and ionization potential of the elements

difficulty of migration of the elements, as a function fo ionization potential.

V. 2 Mineral associations and their forming temperatures

Both the ore deposits and the wall rocks now under consideration are restricted within 200~300m in depth difference and consequently the effect of change in hydrostatic load pressure on mineral associations in the altered rocks may be practically neglected. Assuming the vapour pressure of the environment kept in constant during the time of the major alteration, therefore, the variance in mineral association has to be considered primarily due to the variance in either temperature, concentration of ions, pH of solution, or constituents which participated in the formation of the minerals. The mineral constituents, being

depend upon the composition of the chemical systems in a given environment, might have varied from place to place in the altered aureole, ultimately as a function of continual change of solution which caused also the change in composition of the chemical systems.

Three different kinds of mineral associations are recognized as follows:

- 1) Quartz-sericite-chlorite
- 2) Quartz-sericite-chlorite-carbonate
- 3) Quartz-chlorite-montmorillonite-(carbonate)

The first association represents the rocks of the silicified and clayey zones, the second the rocks of chlorite-carbonate zone and the third the narrow peripheric montmorillonite zone along the sericite veins.

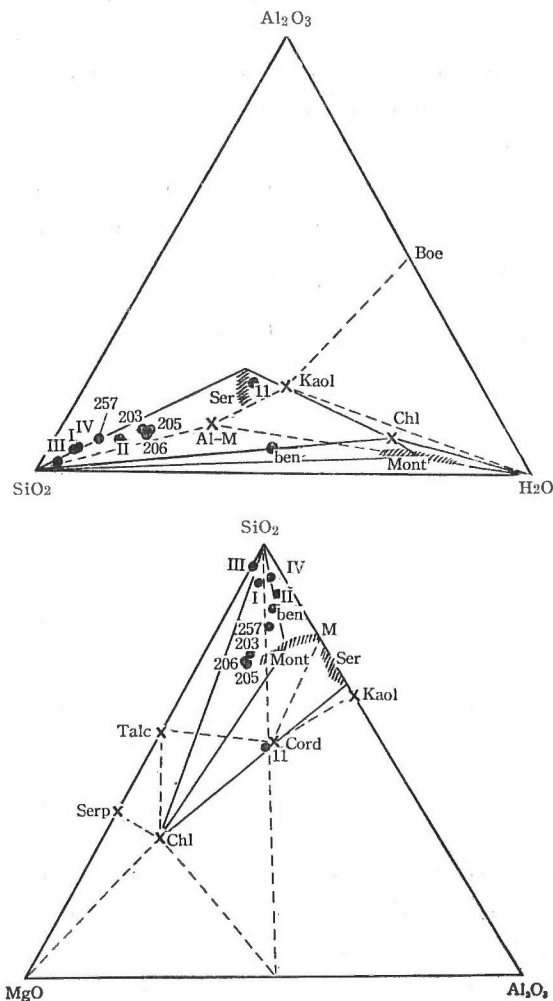
In spite of the great variance from place to place in the mutual abundance of the three or four minerals in each of these associations, the persistency in mineral combination is characteristic. Fig. 18 shows the mineral associations plotted in the phase diagram, $MgO-Al_2O_3-SiO_2$ and $SiO_2-Al_2O_3-H_2O$, respectively.

The experimental results in synthesis of clay minerals obtained by J.W.Grunner (1944)³⁾, H. S. Yoder (1952)¹²⁾, R. Kiyoura(1952)⁴⁾ and also by R. E. Roy and E.F. Osborn(1952)¹¹⁾ show that the association of quartz-kaolinite-chlorite is stable between

approximately 430°C and 350°C at about 150~200 atm. They may suggest a similar PT environment in the presence of sufficient K for the stable association of quartz-sericite. Because, the special tendency for potash to be adsorped in clays in some adequate condition, say for instance in alkaline as well as in hot neutral or acid solutions, is well known. The stable field of montmorillonite, in the presence of sufficient Mg, on the other hand, seeing from the results of experiments performed by H. S. Yoder, R. E. Roy and E. F. Osborn, may be inferred to cover a temperature range from about 100°C to 430°C.

Although we have no experimental information on the adequate pH condition for the co-existence of montmorillonite and chlorite, it is well known that chlorite is stable in alkaline solutions at elevated temperature and pressure, say from 400°C to higher than 550°C, at 15,000 psi.

Assuming the probable depth of the ore formation to be about 2~3 km from the surface, the principal rocks of the altered aureole, which are represented by either of the two mineral assemblages, quartz-chlorite-sericite and quartz-chlorite-montmorillonite, may be inferred, thereby, to have been formed within a very limited range of temperature, approximately between 350°C and 400°C.



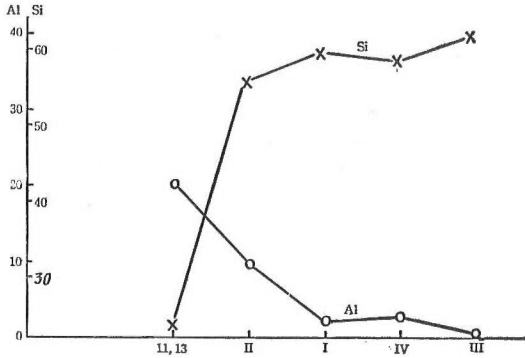
- II, I, IV, III : Rocks of the silicified zone
 II : Rocks of the principal clayey zone
 257 : Fresh aphyric dacite
 203, 205, 206 : Rocks of the chlorite-carbonate zone
 Boe : Boehmite Mont : Montmorillonite
 Kaol : Kaolinite Cord : Cordierite
 Chl : Chlorite Ser : Sericite
 Serp : Serpentine M : Montmorillonite
 ben : Rocks of the bentonite layer
 Al-M : Aluminous montmorillonite
 Talc : Talc

Fig. 18 Chemical composition of the altered rocks plotted in Al_2O_3 - SiO_2 - H_2O and SiO_2 - MgO - Al_2O_3 systems. The full lines illustrate the actual phase assemblages, whereas the broken lines the assemblages proved experimentally stable in the systems (with potash-deficient) at about 4,000 C and 15,000 psi.

V. 3 Effect of change in pH of solutions on forming the zonal distribution of the altered rocks

As previously mentioned, in a number of places in the altered aureole, porous silica rock is enveloped by compact silica rock and still further by the rocks of the clayey zone.

With respect to the relative abundance of Al_2O_3 and SiO_2 , it becomes evident that Al_2O_3 is markedly high in the clayey zone and very low in the silica zone.



11, 13 : Rocks of the principal clayey zone
 II, I, IV, III : Rocks of the silicified zone
 The rocks marked as III is presumed to be nearest to the conduit.

Fig. 19 Variation diagram showing the relative abundance of Si and Al with respect to the distance from the presumed conduit of the ascending solution (calculated as O=160)

Extremely low Al_2O_3 percentage in the porous silica rock may be worthy in special attention, because it is an evidence of nearly complete removal of elements including Al_2O_3 , other than SiO_2 from the rocks near around the conduits of ascending solutions, leaving silica behind, and also of the subsequent deposition of these elements at the outer clayey zones.

The relative abundance of silica in the alteration aureole is roughly in converse relation to Al_2O_3 . Silica which was subtracted in considerable extent from the rocks of the clayey

zone seems to have added to and deposited at the inner zone giving rise to the silicified rocks which are somewhat higher in silica content than the original rocks. The variation curves of Si and Al as a function of departure from the porous silica rock, i. e. from the conduits of ascending solutions are represented in Fig. 19.

Seeing from a general mechanism of concentration, migration, and precipitation of elements in solutions,⁹⁾ the curves may be taken as having relation to the change in solubility of SiO_2 and Al_2O_3 as a function of the distance from the conduits. The more soluble the oxides are, the less concentrated are they in the altered products, and then, the less soluble, the more concentrated.

If so, what factor did control primarily the solubilities of Al_2O_3 and SiO_2 in the altered aureole? It is well known⁹⁾¹⁰⁾ that the solubilities of SiO_2 and Al_2O_3 vary greatly with respect to pH of the environment, at a given temperature. At pH=4, alumina is readily soluble, whereas silica is only slightly soluble. At pH=5~9, the solubility of silica increases considerably but alumina is practically insoluble. (Fig. 20) In the present case, under the assumed probable environment with temperature and pressure both kept practically in constant, pH might be the most significant function of the solubility.

Near around [the presumed conduits, now occupied by the porous silica zone, therefore, pH of the environment might be concluded as lower, for instance approximately 4~5, whereas toward the outside, it might become higher, say, probably 5~7 at the clayey zone.

If, on the contrary, the change in temperature was of prime importance in giving influence to the solubilities of the elements, and the temperature gradient declined toward the peripheric zone of alteration, the concentration of the elements in the altered rocks might be given in a converse relation, at least concerned with SiO_2 .

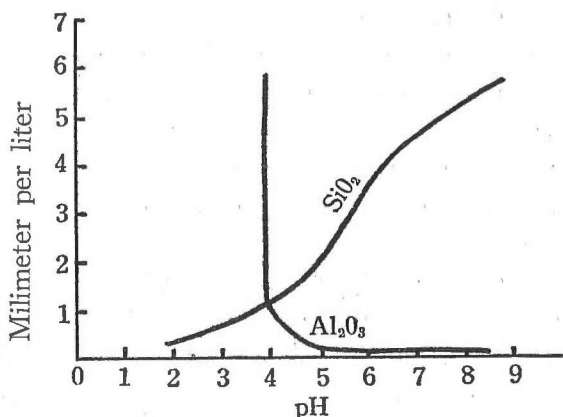


Fig. 20 The solubility of silica and alumina as a function of pH (cited from B. Mason: Principles of Geochemistry, 1951)

declined toward the peripheric zone of alteration, the concentration of the elements in the altered rocks might be given in a converse relation, at least concerned with SiO_2 .

V. 4 Nature of the solution and the rock alteration

It is beyond of the present scope to discuss the detailed nature of the ascending solution. Because, we have not any sufficient data for dealing with this problem.

Since there is a clear evidence of the addition of H, C, S, Ba, Fe, Cu, Pb, Zn and Ag from outside to the alteration aureole, it may be quite natural to presume a ascending hydrothermal acid solution containing CO_2 , H_2S , S, SO_3 and probably metal-chloride such as FeCl , etc., as suggested by N. L. Bowen.¹⁾ Such acid solution being capable of carrying the elements other than SiO_2 into solution might react with the fresh dacite, might leave SiO_2 behind as porous rock and might become itself gradually less acidic containing such as K_2CO_3 , Na_2CO_3 , NaHCO_3 , FeS_2 and so on.

It might be because of moderate enrichment of potash in the solution, that sericite, instead of kaolinite, was formed in the siliceous zone at the presumed temperature 350~400° C.

The solution, on migrating further outward, might gain a more alkaline nature enriched with elements other than silica, whereas Al_2O_3 for instance might combine with the other elements to deposit as sericite and chlorite.

Silica, on the contrary, was carried largely into solution in such a alkaline reagent, migrated inward where silica was practically insoluble and very dilute in solution and deposited there quartz of the siliceous zone.

Allied examples in which the early acid nature of the ore forming solutions of hypogene origin changes to alkaline in later stage are not rare in other countries.

A part of MgO was expelled from the alteration, concentrated and fixed as either chlorite or montmorillonite minerals in the outermost zone of alteration. A part of

CaO behaved almost similarly, but was fixed as calcite and gypsum either in the rocks of the outermost zone or in the cap rock.

The paragenetic relation of the sulphide minerals with the clayey and silica minerals is also important for understanding the nature of the ascending solution as cited in the preceding pages, but closer examination of the metallic ores and additional investigation on the gangue minerals may be required for completing the studies.

One of the facts which is worth to particular attention is the relation between the porosity of the altered rocks and the distribution of the ore shoot as given in Fig. 8. The ore shoot seems to be restricted to the rocks of high porosity. Although it may be quite hazardous to conclude that the porosity is of prime importance as a function of susceptibility of the rocks for solution, it may be taken as being similarly important as the network fractures or open cavities in the rocks.

Conclusions

From the studies on the altered wall rocks of the Kosaka mine, the present authors arrived at some conclusions about the environment and the mechanism of an example of the hydrothermal alteration related to the formation of epithermal replacement copper-lead-zinc ore-deposits in Tertiary acid volcanic rocks.

- 1) The original rock is dacite or dacitic rhyolite.
- 2) The limited mineral assemblages are characteristic in the altered rocks, and consequently it may be inferred that alteration took place within narrow range of temperature, say about 350~400° C, at the presumed depth of about 2~3 kilometers.
- 3) Assuming such restricted PT environment, the change of pH of the solution with respect to the distance from the conduit is considered to be the factor of prime importance for defining the zonal arrangement of the altered rocks, the silica zone at the core, and the clayey zone at the mantle. This comes from the well known fact that the solubility of oxides in a solution is a function of pH. SiO₂, for example, is very low in solubility at low pH, whereas Al₂O₃ is nearly insoluble at high pH.
- 4) From what just mentioned, the ascending solution might be considered as having started from somewhat acid nature and increased its pH taking the elements of the wall rocks into solution during its lateral migration in the wall rocks.
- 5) The order of concentration of elements with respect to the distance from the center of the altered aureole coincides roughly with the order of ionization potential of the elements with a few exception.
- 6) Kaolinitic alteration of sparse distribution is superimposed on the general alteration. It is of far later geologic period.

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要 約

秋田県小坂鉱山の母岩の変質

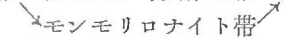
岩生周一・岸本文男・高橋 清

筆者等は1951年10月、約20日間にわたつて、秋田県小坂鉱山の黒鉱鉱床の母岩の変質の状態を明らかにする目的で、主に露天掘跡と現在沈澱銅採取の対象となつている珪化区域を中心として野外および坑内調査を行い、その後室内研究を行つた。その結果明らかにされた事実および推論されることは次の通りである。

1) 黒鉱・黄鉄鉱の生成とその母岩の変質とは、ほとんど同時に行われ、赤森凝灰岩層の緑色凝灰岩を帽岩とし、主にその下位の荆森角礫凝灰岩中に認められる。

2) 黒鉱・黄鉄鉱・珪化の配列方向、これを取巻く変質帯の延長方向、変質帯を貫ぬく幾條かの侵入角礫岩の方向はいずれもNE-SWであつて、この方向に鉱化作用が繰返されたことを示す。

3) 変質帯はかなり不規則な輪廓を持つが、大体次の順序で内側から外側へ向つて累帯配列を示している。

多孔質珪化帯→珪化帯→漸移帯→緑泥石・絹雲母粘土帯→
緑泥石・方解石帯→原岩(石英安山岩)

4) 珪化帯は少量の絹雲母と微量の緑泥石とを含むから、結局変質帯全体は絹雲母・緑泥石・モンモリロナイトなど、H. S. Yoder などの実験によれば、約150～200気圧では、350～450°C内外で生じ得る粘土鉱物で特徴付けられている。産状から見て変質帯の中心部と周辺部とで圧力の変化の影響はほとんど考えられない。

5) 変質帯全体として、ほとんどそのなかに留つている成分はSi, Ti, ほとんど完全に取去られた成分はNa, Rb, Sn, Li, Caの一部、変質帯内に若干取残され部分的に濃集していると推定される成分はAl, Mg, K, Mn, Vであつて、明らかに添加された成分はFe, H, Ba, C, Ag, Cu, Zn, Pb, Sである。こゝで変質帯全体から除去され方の難易の順序に従つて成分を配列すると、

$Ti, Si > Al, K, Mn, V > Mg, Ca > Na, Rb, Sr, Li, (Ca)$

の如くであり、KとMnとの例外を除くと、各元素のイオン化ポテンシャルの順位と一致している。このことは変質作用に当つて熱水溶液が支配的役割を演じたことを暗示する。

6) 変質帯内における成分変化のうち、最も顕著なことは中心部ほど珪酸に富み(多孔質珪化帯で代表される残存珪酸分)、周辺部に向つてアルミナが濃縮していることである。この事實は変質作用に際しての環境が、中心部では比較的pHが小で、周辺部ではpHが大であつたことを推定させる。

7) この環境の変化は変質作用に与つた熱水溶液が、中心から外側へ向つて母岩と反応しつゝ浸透し、時間が経過するうち、酸性から次第にアルカリ性へと変化したことを物語つている。

8) 鉛・亜鉛を主とする黒鉱鉱床が緑泥石絹雲母粘土帯、すなわちアルミナの濃集した部分に包まれていることは、この鉱床が鉱液が相当アルカリ性になつたときに初めて沈澱したことを示唆する。

PLATES
AND
EXPLANATIONS

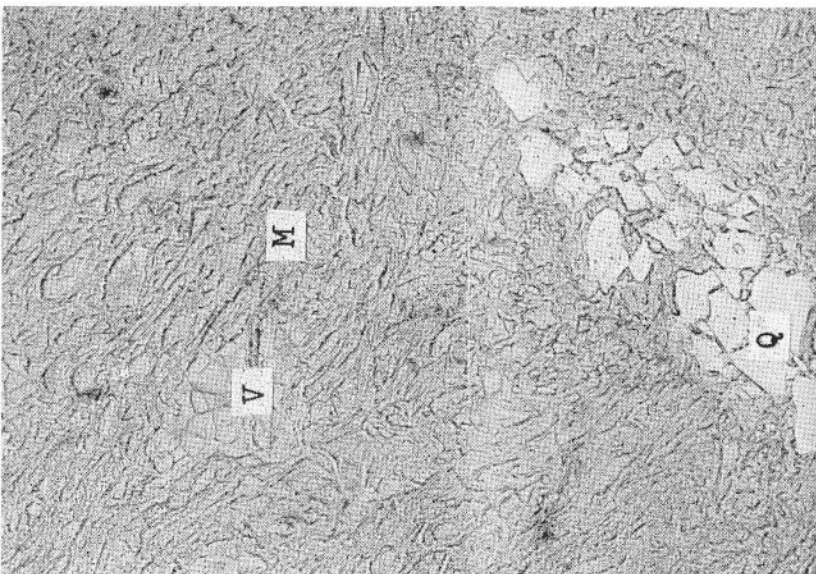


Fig. 1. Vitreous dacite flow partly altered into bentonitic clay, no. 279.
Q : Quartz phenocrysts crushed into small grains
M : Aggregates of montmorillonite clay following fluidal texture
V : Fresh vitric glass polarizer only, $\times 30$

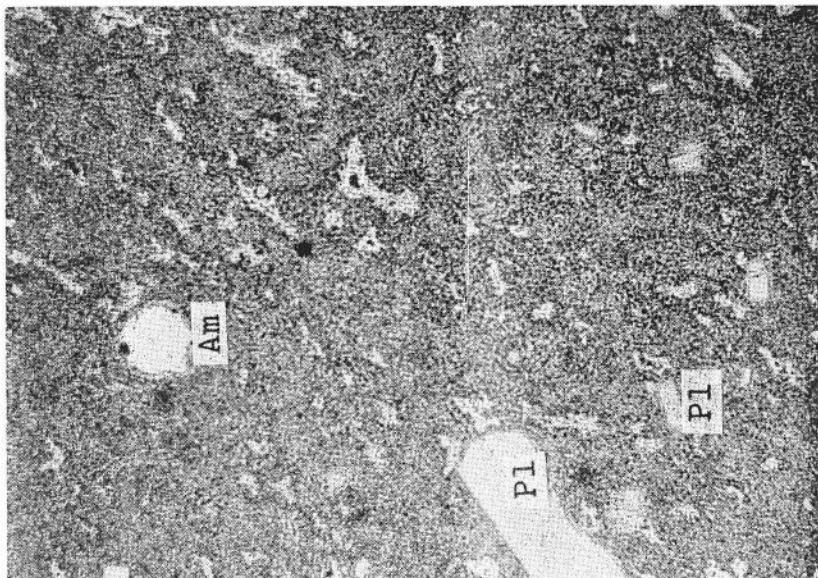


Fig. 2. Apphyric dacite, no. 257.
Pl : Plagioclase
Am : Amygdaroidal cavity filled by quartz polarizer only, $\times 21$

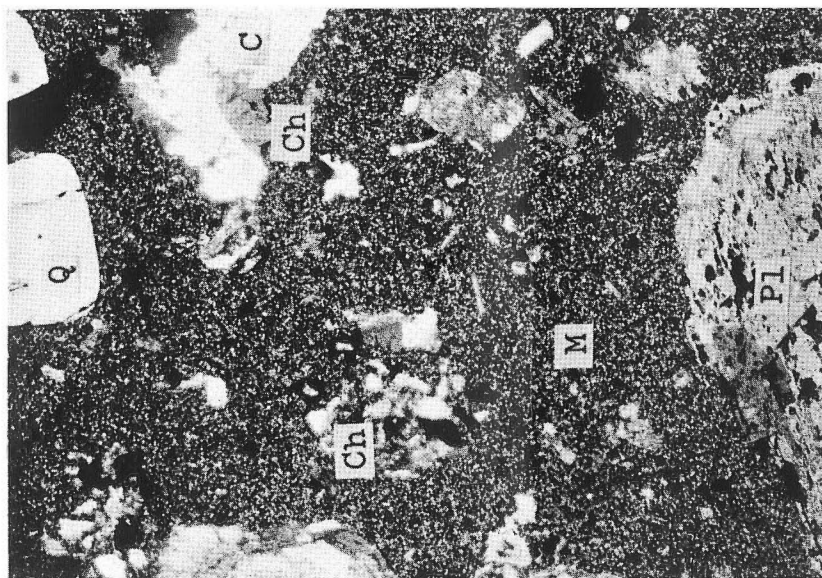


Fig. 3. Akamori porphyritic dacite, no. 197.

- Q : Quartz
 - C : Aggregates of calcite
 - M : Groundmass
 - Ch : Aggregates of chlorite
 - pl : Plagioclase
- crossed nicols, $\times 21$

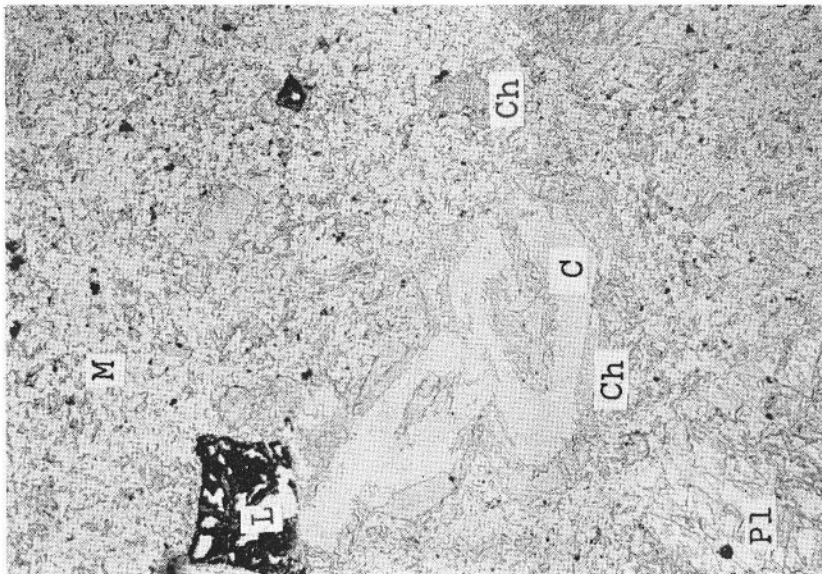


Fig. 4. Slightly altered Akamori dacite, no. 203.

- Pl : Plagioclase partly altered
 - Ch : Aggregates of chlorite
 - C : Aggregates of calcite after plagioclase, rimmed by chlorite
 - M : Groundmass
 - L : Leucoxene
- polarizer only, $\times 30$

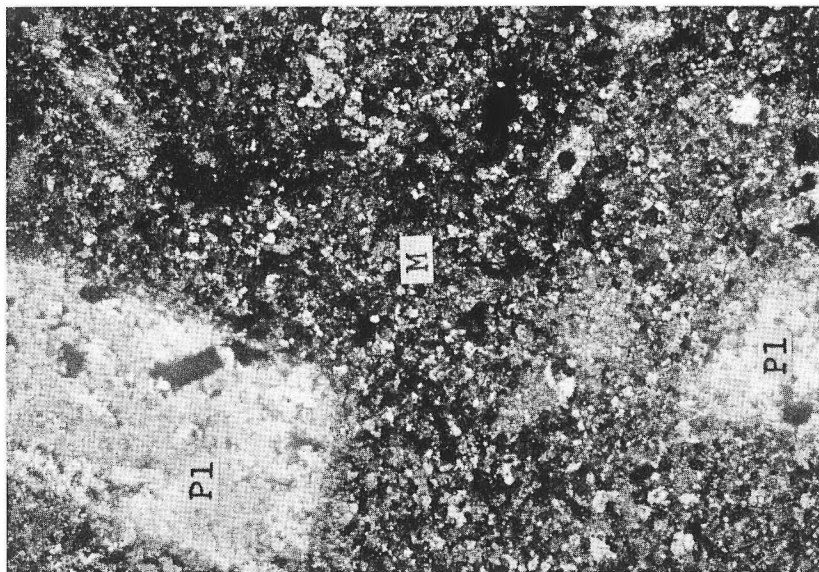


Fig. 5. Weakly silicified and argillized dacite, no. 177.
Pl : Altered plagioclase phenocryst
M : Altered groundmass
crossed nicols, $\times 21$

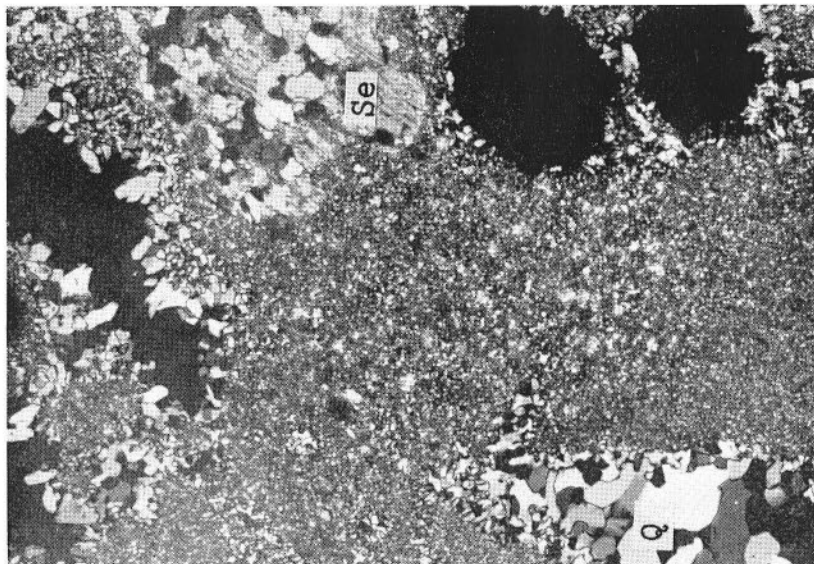


Fig. 6. Compact silica rock, no. 177.
Se : Aggregates of sericite and quartz after
plagioclase phenocryst
Q : Coarse grained quartz pool
crossed nicols, $\times 21$

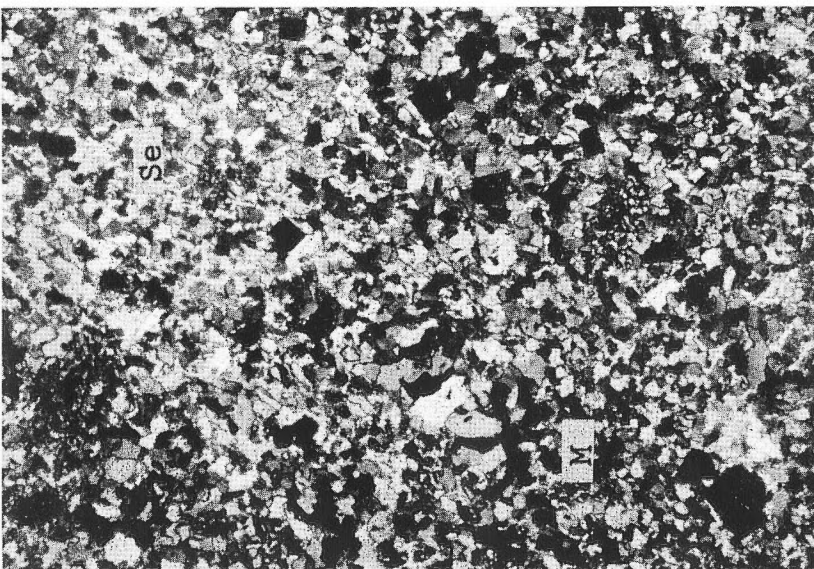


Fig. 7. Moderately silicified dacite, no. 136.
Se : Highly poikilitic aggregates of sericite
after plagioclase phenocryst
M : Siliceous matrix after groundmass
crossed nicols, x21

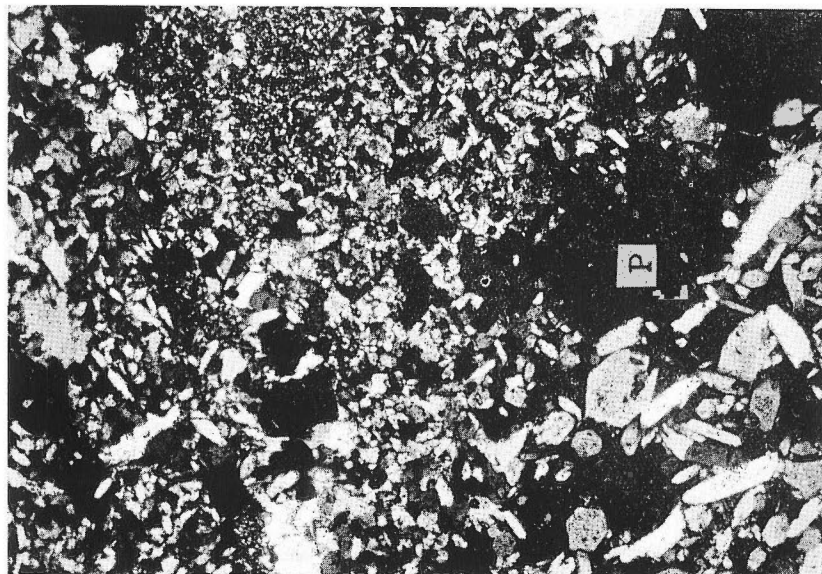


Fig. 8. Porous silica rock, no. 66.
P : Cavity rimmed by aggregates of coarse
grained quartz
crossed nicols, x21

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|------------------------------|---|---|
| A. Geology & allied sciences | } | a. Geology.
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- | | | |
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| A | 地質およびその基礎科学に関するもの | a. 地質
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e. 地球物理
f. 地球化学 |
| B | 応用地質に関するもの | a. 鉱床
b. 石炭
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d. 地下水
e. 農林地質・土木地質
f. 物理探鉱・化学探鉱および試錐 |
| C | その他 | |
| D | 專業報告 | |

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昭和 29 年 11 月 5 日印刷

昭和 29 年 11 月 10 日発行

著作権所有 工業技術院
地質調査所

印刷者 田 中 春 美

印刷所 田中幸和堂印刷所

東京都台東区東黒門町 3 番地

